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Boundary Detection Criteria for Satellite Altimeters

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Section 1.0
INTRODUCTION

All oceanographic satellites which have been operated and considered for operational systems have included a radar altimeter as one of the primary instruments. A microwave altimeter can provide precise sea surface topography along the satellite groundtrack under nearly all weather conditions. In addition, return waveform measurements can provide significant wave height (SWH) measurements along the groundtracks and signal strength measurements (AGC) can provide wind speed estimates. However, because of the finite altimeter footprint size and various lags in the on-board data processing, all measurements are to some degree averages of conditions along a swath along the groundtrack and may be significantly affected by conditions and terrain a footprint or more away from the instantaneous subsatellite point. Thus, measurements taken when the satellite is over water but close to land may be affected by the terrain and may not be reasonably accepted as producing valid sea surface heights, significant wave heights, or wind speeds. Although it is conceptually possible to provide the altimeter processing with land masks, the inclusion of every small island, or even a high level of detail in continental land boundaries, is simply not practicable.

In addition to land contamination of altimeter measurements in the vicinity of land-water boundaries, there are similar problems in the vicinity of ocean-ice boundaries. Here, in general, ice maps would not be available with sufficient accuracy to perform data editing, so the use of the altimeter data itself as a boundary detector is perhaps the only recourse if it is desired to salvage and utilize all valid data over ocean. In fact, the detection of ice boundaries would be a useful altimeter function.

There are two other aspects of data contamination which must also be considered. The first of these is the distance from land (or ice) which the subsatellite point must be in order for the measured data to produce true ocean parameters. This distance may differ for the different data products, and also between crossings onto and off land or ice. Secondly, there may be situations in the open ocean for which the altimeter data products are not valid, due to the surface conditions for which the altimeter was not designed to - and does not - satisfactorily operate. It is highly desirable that such data either be edited or at least flagged as being of dubious quality. Otherwise, the number of identified regions with 100 mile/hour winds may increase drastically.

This report provides the results of a limited investigation of Seasat data in the vicinity of land and ice boundaries, with the objective of determining useful - and hopefully simple - indicators of boundary crossings based on the altimeter data alone. Most of the crossings investigated have been onto land or ice, in part because it appeared that data characteristics crossing onto water were such that different indicators would be necessary than for the water - land/ice crossings. The conclusions that can be drawn from these investigations, and the indicated course for validating reliable flags for both types of boundary crossings, are given in Section 5.

Section 2.0
BOUNDARY DETECTION CRITERIA

There are two somewhat different interests in the development of boundary detection criteria. One of these is for surface mapping, such as in the determination of ice field boundaries. The other interest is due to the need for data editing in the vicinity of boundaries where one or more of the altimeters data products may become degraded. Although the "boundary" associated with the latter interest is not synonomous with a true boundary crossing, it may be more convenient to approach the detection problem by looking for indications of a true boundary crossing. This is suggested by the fact that data degradation in the vicinity of a boundary is gradual and significant contaminated data could be admitted while waiting for the bad data threshhold to be crossed. Thus, in principle, if a boundary crossing could be reliably identified from the data, then a data editing algorithm could consist of deleting the previous (or subsequent) Δt seconds of data.

All altimeter raw data products included in the telemetered data stream are potential candidates for use for contamination sensing. These products include (all available at a 10/second data rate for the SEASAT data to be considered)

- Altitude (sea surface height)
- Altitude rate
- Height error
- SWH
- Waveforms
- AGC

Considering that the detection algorithm should be as simple as possible to implement, not all of the data items above are of equal interest. In addition, reliability must be factored in as being more important than simplicity. However, reliability must be defined in terms of the satellite project guidelines. In general, we would like to detect all crossings from ocean onto some other terrain (land,ice) with a near 100% probability, so that data from non-oceanographic regions is not distributed as oceanographic data. The rapid detection of boundary crossing onto ocean is not nearly so critical for editing purposes since the result is only to effectively delete a small amount of potentially good oceanographic data. In many cases, the altimeter will have had to re-acquire lock after transition onto water, with no loss of good data.

The desirability of a high probability of detection suggests that a large portion on all of the data products may be needed, so that multiple boundary detection indicators may need to be considered. Whether multiple indicators should be used in the AND or OR mode* must be based on the analysis of real data.

The altimeter data types listed above include the basic measurements of height (altitude), return pulse shape, and return signal strength. Considering the height related parameters (height, height rate, and height error), some height change must be detectable at the boundary, or else this type of indicator cannot work. Height rate and height error are thus more promising candidates for direct utilization as detectors than is the height measurement. And height error would be expected to show the sharpest boundary variation change, since it is a direct measurement rather than being filter output as are both height and height rate. The primary concern here would be for those boundaries for which the height variation at a coastline would be so gradual that the altimeter tracker would have minimal difficulty following the surface topography and correspondingly never have an anomalously large height error. However, given the Seasat altimeter's general history of tracking difficulties over land, height tracking problems at land boundaries would be the normal expectation.

Return pulse waveform information is obtained from the Seasat altimeter in the form of 0.1 second averages, and also in the form of an on-board computation of SWH. If waveform information is to be used for boundary detection, certainly SWH data would be preferred over the full waveform data, simply because of the smaller amount of data. However the computed SWH is based on a relatively small portion of the total return waveform and some region other than the ramp may be a more suitable boundary detector. In fact, based on GEOS-3 experience, the attitude/specular gate data - far out on the waveform - would be expected to be a reliable boundary

* I.e., whether a boundary decision will be positive when Test A and Test B are passed, or whether the decision will be positive when either Test A or Test B is passed.

detector. However, since the attitude/specular gate on the Seasat altimeter had questionable calibration and was frequently saturated, it is not possible to verify this using Seasat data. Consequently, this study will exclude the use of such data as a boundary detector. Only for situations where nothing else works will we reconsider its utilization.

The third type of altimeter measurement, return signal strength or AGC data, is potentially usable in the boundary detection process, since the scattering cross sections for ocean and land (or ice) are generally quite different, as was clearly demonstrated by the GEOS-3 altimeter data (Miller, 1979). There are at least two problems with AGC data, however. First, the return is based on a large footprint size, so the variation at a boundary will be gradual rather than sharp. Secondly, AGC behavior in general is probably not as well understood as is return pulse shape and AGC "anomalies" can occur frequently. For these reasons, we would expect that AGC could be used in some way for boundary confirmation, but probably not as the primary indicator.

Finally, we must consider the probability that boundary detection criteria will lead to false boundaries. This means that various regions and various sea state conditions must be investigated for the open ocean to determine that they would not be accidentally flagged as land or ice areas. Such investigations will be restricted to regions of high height acceleration and regions of very high sea state. Such regions should provide the greatest difficulties for the height tracker.

Section 3.0

WATER TO LAND BOUNDARY CROSSINGS

The detection of altimeter footprint crossing from water to land is one of the major boundary detection problems, since it is a transition from good oceanographic data to invalid data and failure to detect a boundary would result in the computation and distribution of invalid sea surface parameters. Failure to detect a land to water boundary, on the other hand, would simply result in lost data - undesirable but probably causing only minor problems for an operational satellite if the detection is simply late.

As discussed in Section 2, the data type considered to be the most promising as a sharp boundary detector is tracker height error. This is expected on the basis that the altimeter tracker, using predicted altitudes based on the slowly varing ocean surface, will encounter topography at the ocean-land boundary that is "significantly" different from the ocean. The difference between the predicted topography and the topography based on a 50 msec averaged waveform is, by definition, the height error.* The questions that then arise are:

- What amount of height error typically exists at a water-land crossing?
- What level of height error can be expected over open ocean under anomalous conditions - e.g., from regions of high sea state?
- Can a height error level be found that will be a reliable boundary detector without tripping or giving false alarms over open ocean?
- If the height error is an effective boundary indicator, what is the magnitude of the height error that says a water-land boundary has been crossed?
- Should both positive and negative height errors be given equal consideration, or are negative height errors always encountered first?
- By what amount (in time or distance) is a height error boundary indicator offset from the point at which invalid altitude, wave height, or wind speed data begins to be produced? That is, how

* Only an average of two such height errors is available for analysis, but this will only tend to smear the boundary slightly.

much earlier than the indicated boundary crossing should data be edited?

To varying degrees, all these questions will be addressed in this section. The approach will be to examine Seasat crossings from ocean to various types of terrain, plus observing data characteristics over ocean under anomalous conditions.

3.1 Seasat Height Errors for Ocean to Land Crossings

Seasat height errors at ocean-land boundary crossings have been investigated from two aspects. First, multiple crossings of very nearly the same water-land boundary have been investigated using crossings of Bermuda during the Seasat calibration period. The objective here was to see the pass to pass repeatibility of data characteristics for the same terrain crossing. The second type of crossing was for different land regions.

Figures 1-7 show the sea surface height and height error for seven approximately overlapping passes across Bermuda. In all cases, a negative height error of several meters is observed within 0.1 - 0.2 seconds of the land boundary. In several cases, however and particularly on September 19 (Figure 2), the height error tends to go significantly positive before going negative. This behavior is associated with a decreasing sea surface height which does not appear realistic for a coastal region. The measured altitudes are thus physically unrealistic for at least a few tenths of a second prior to the land crossing. The determination of a specific number for the time between the end of good data and the boundary crossing indicated by the height error will have to be considered later.

Figures 8 - 17 show the sea surface heights and height errors measured by the Seasat altimeter across ocean-land boundaries for various coasts around the world. In all cases, a height error of at least 1 m in magnitude is observed near the coastal boundary crossing. For the two passes shown across coastlines of Puerto Rico (Figures 8 - 9) and the two passes across coastlines of South America (Figures 10 - 11), the height errors show sharp changes around the boundary crossings, and the height errors have a negative sign. A similar pattern is also observed for the first two passes across Tasmania (Figures 12 - 13). For the other two passes across Tasmania

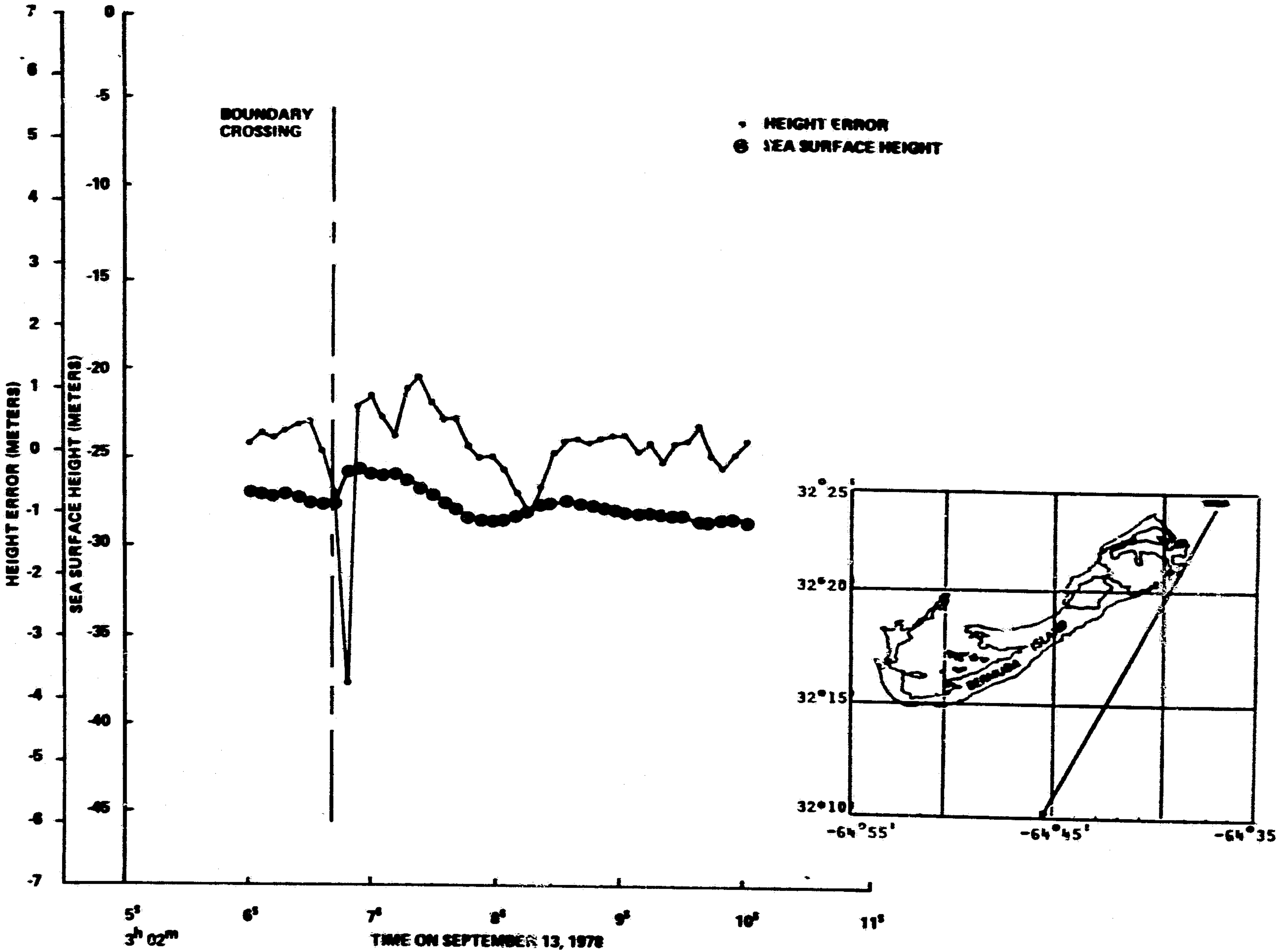


FIGURE 1. SEA SURFACE HEIGHT AND ALTIMETER HEIGHT ERROR FOR SEASAT CROSSING OF BERMUDA

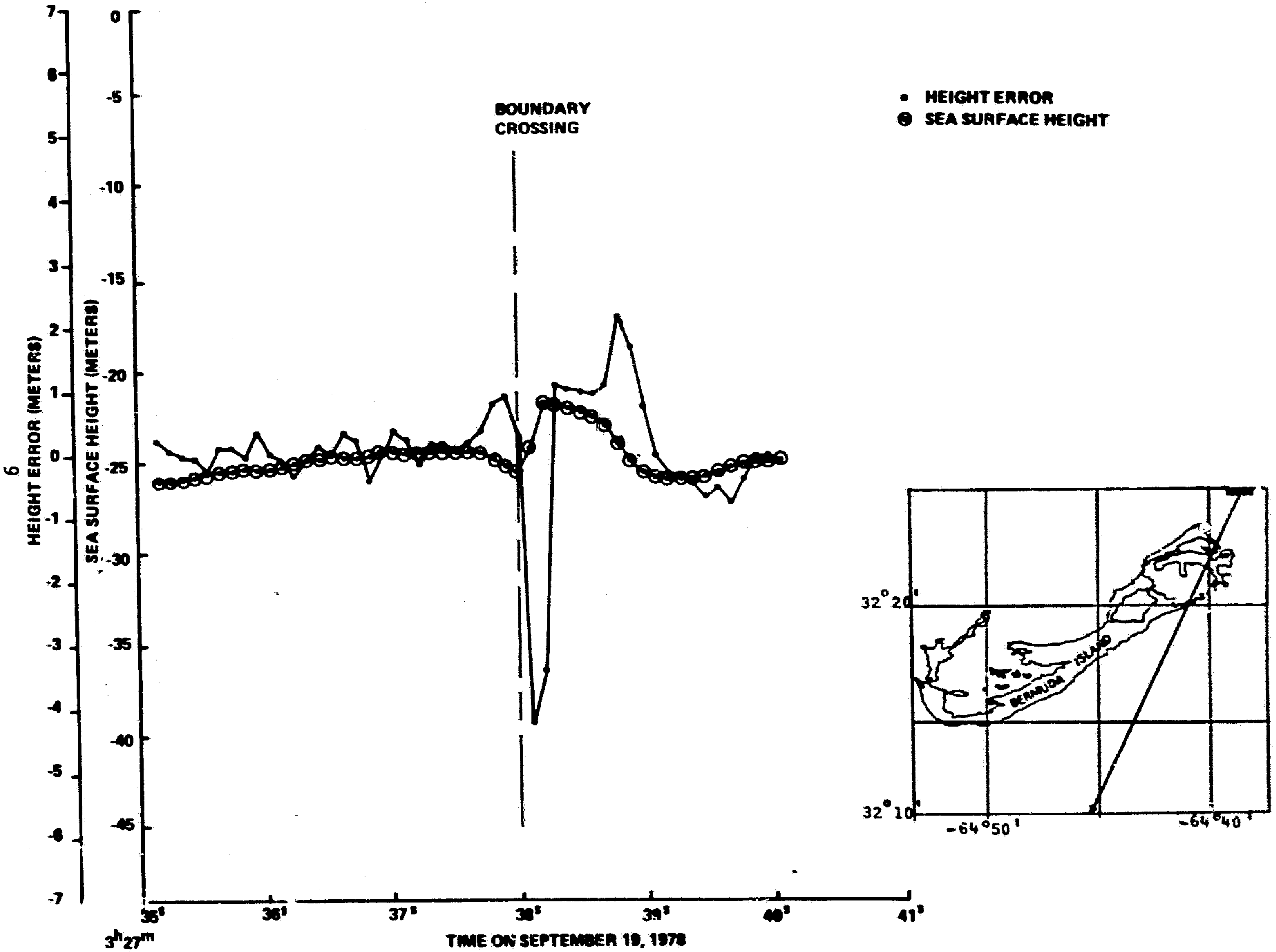


FIGURE 2. SEA SURFACE HEIGHT AND ALTIMETER HEIGHT ERROR FOR SEASAT CROSSING OF BERMUDA

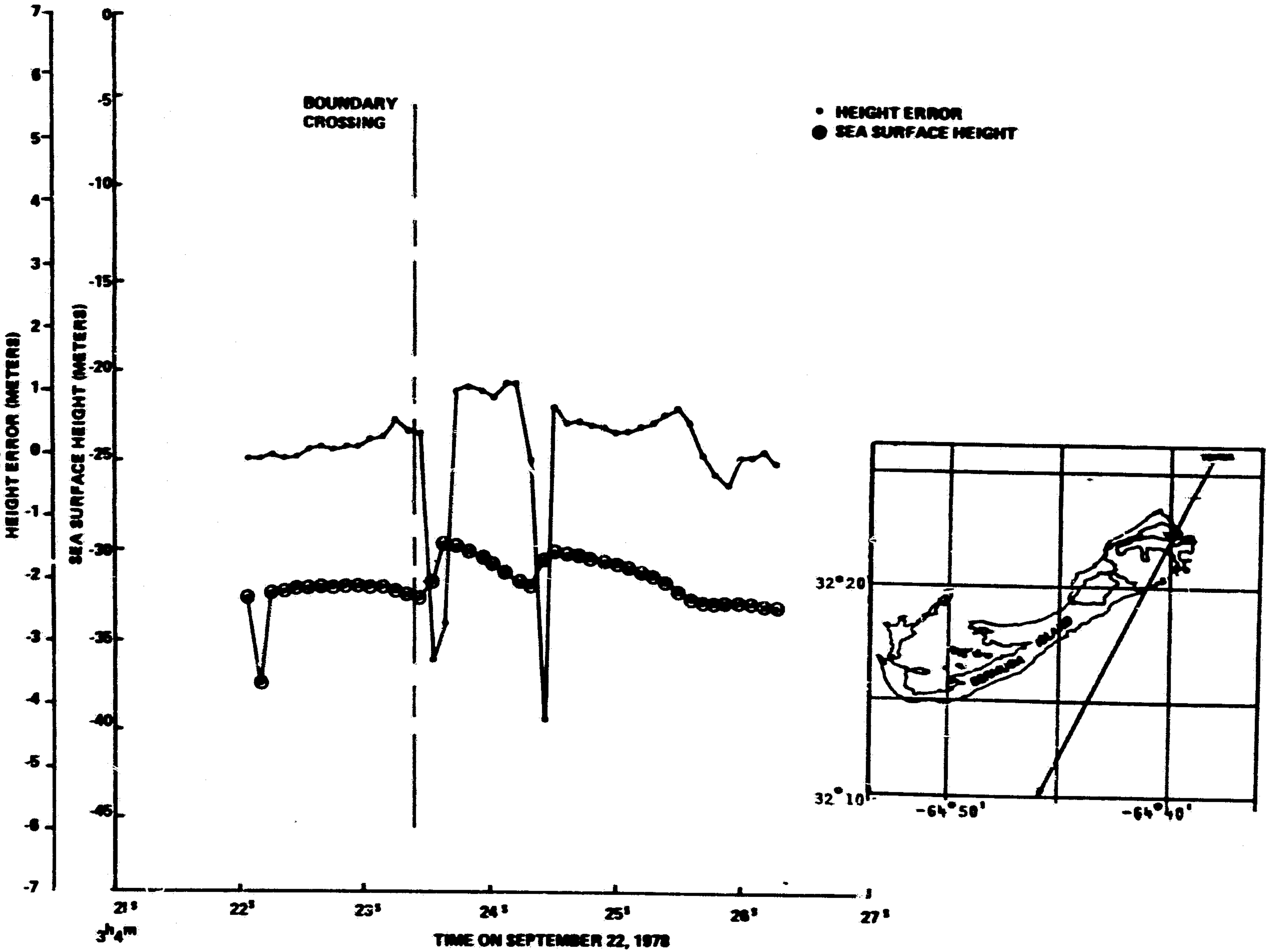


FIGURE 3. SEA SURFACE HEIGHT AND ALTIMETER HEIGHT ERROR FOR SEASAT CROSSING OF BERMUDA

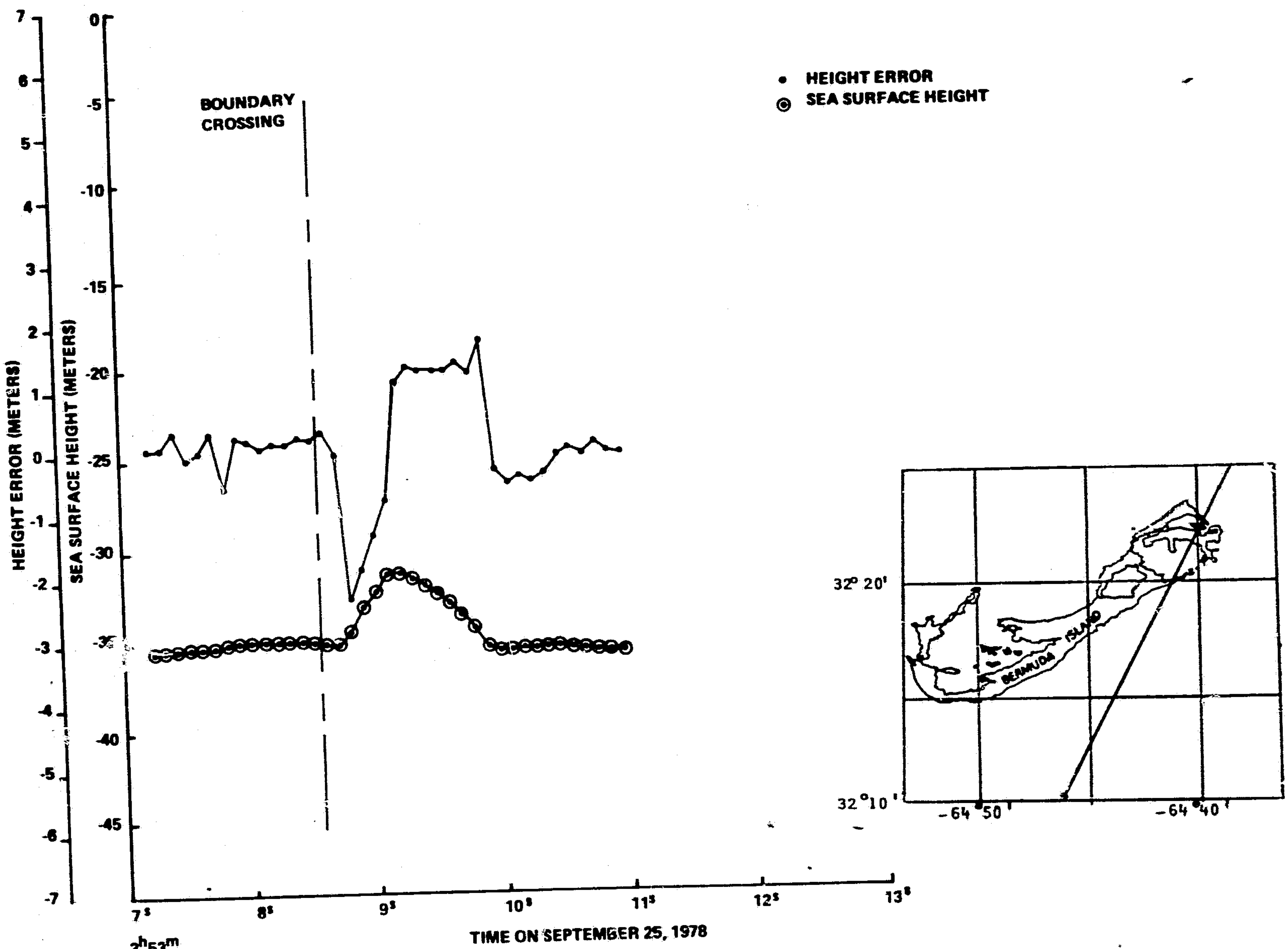


FIGURE 4. SEA SURFACE HEIGHT AND ALTIMETER HEIGHT ERROR FOR SEASAT CROSSING OF BERMUDA

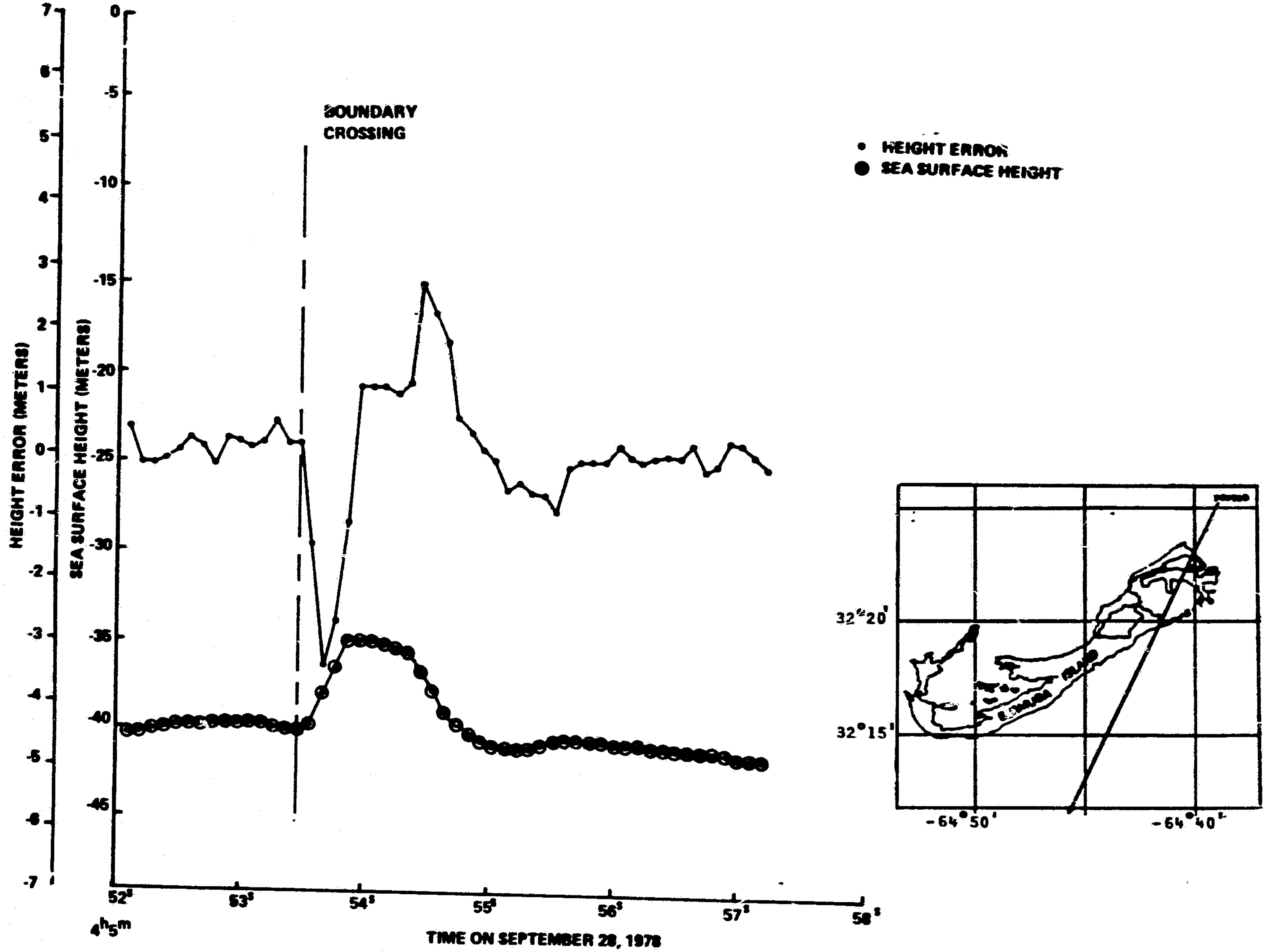


FIGURE 5. SEA SURFACE HEIGHT AND ALTIMETER HEIGHT ERROR FOR SEASAT CROSSING OF BERMUDA

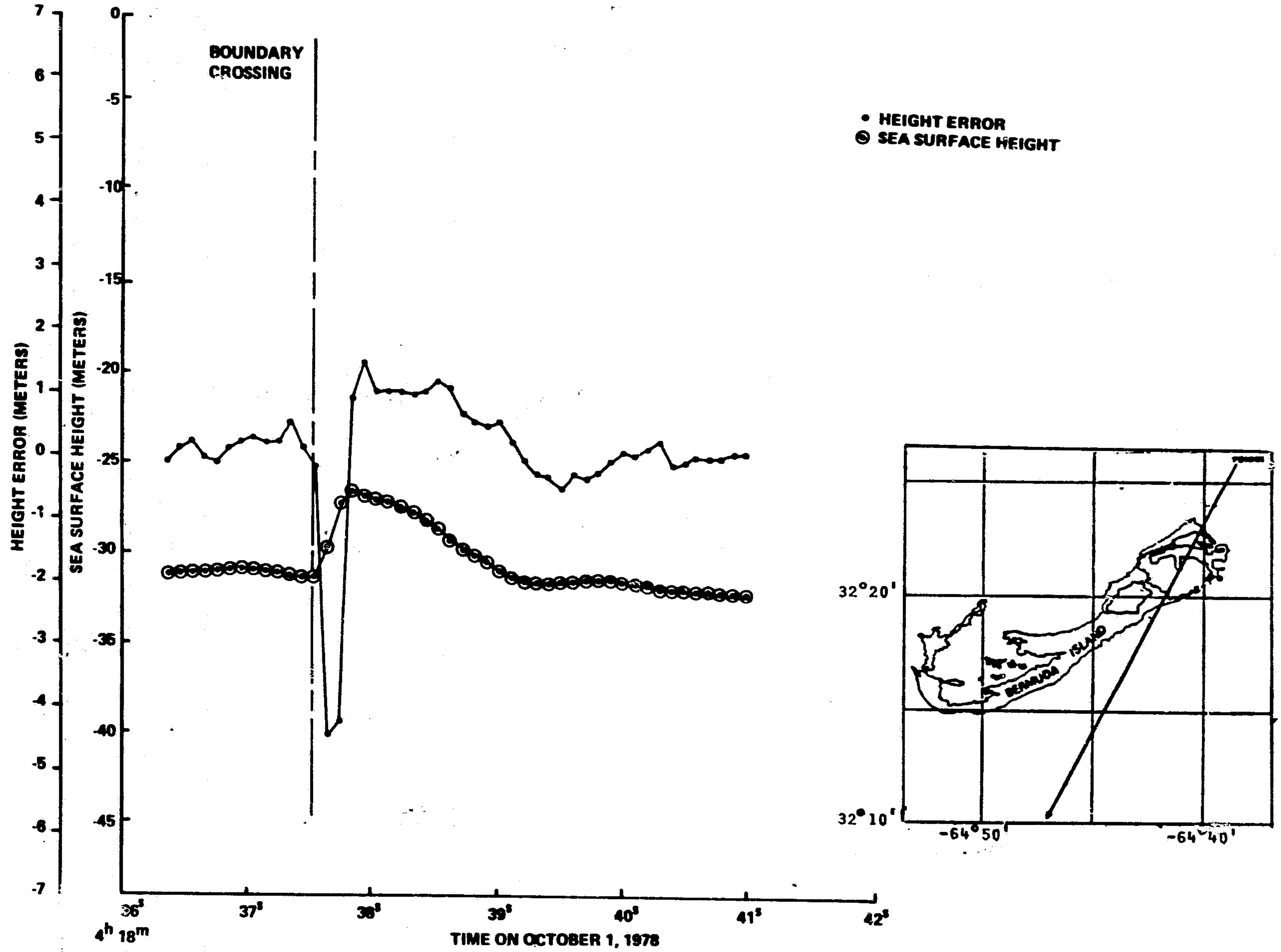


FIGURE 6. SEA SURFACE HEIGHT AND ALTIMETER HEIGHT ERROR FOR SEASAT CROSSING OF BERMUDA

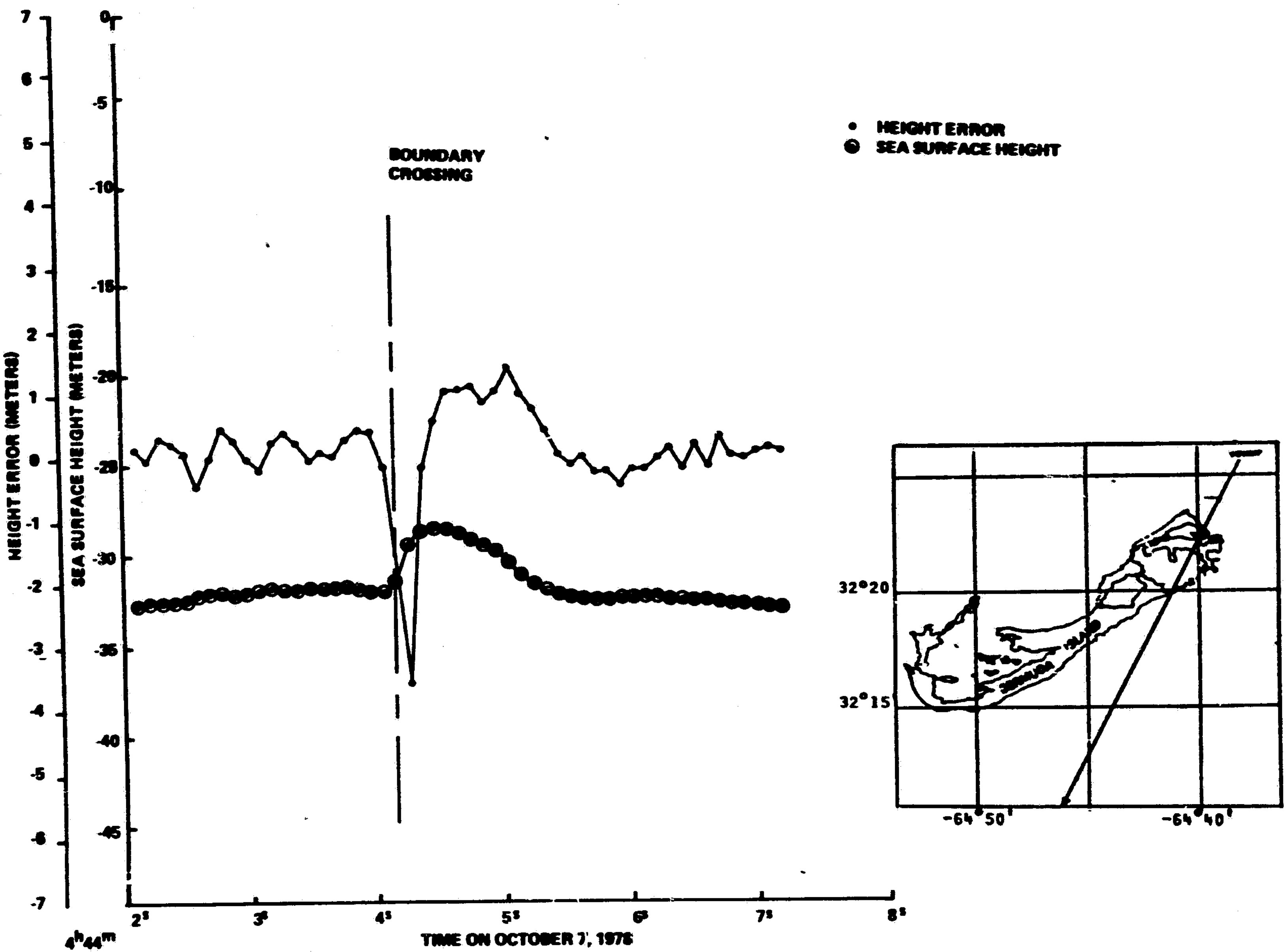


FIGURE 7. SEA SURFACE HEIGHT AND ALTIMETER HEIGHT ERROR FOR SEASAT CROSSING OF BERMUDA

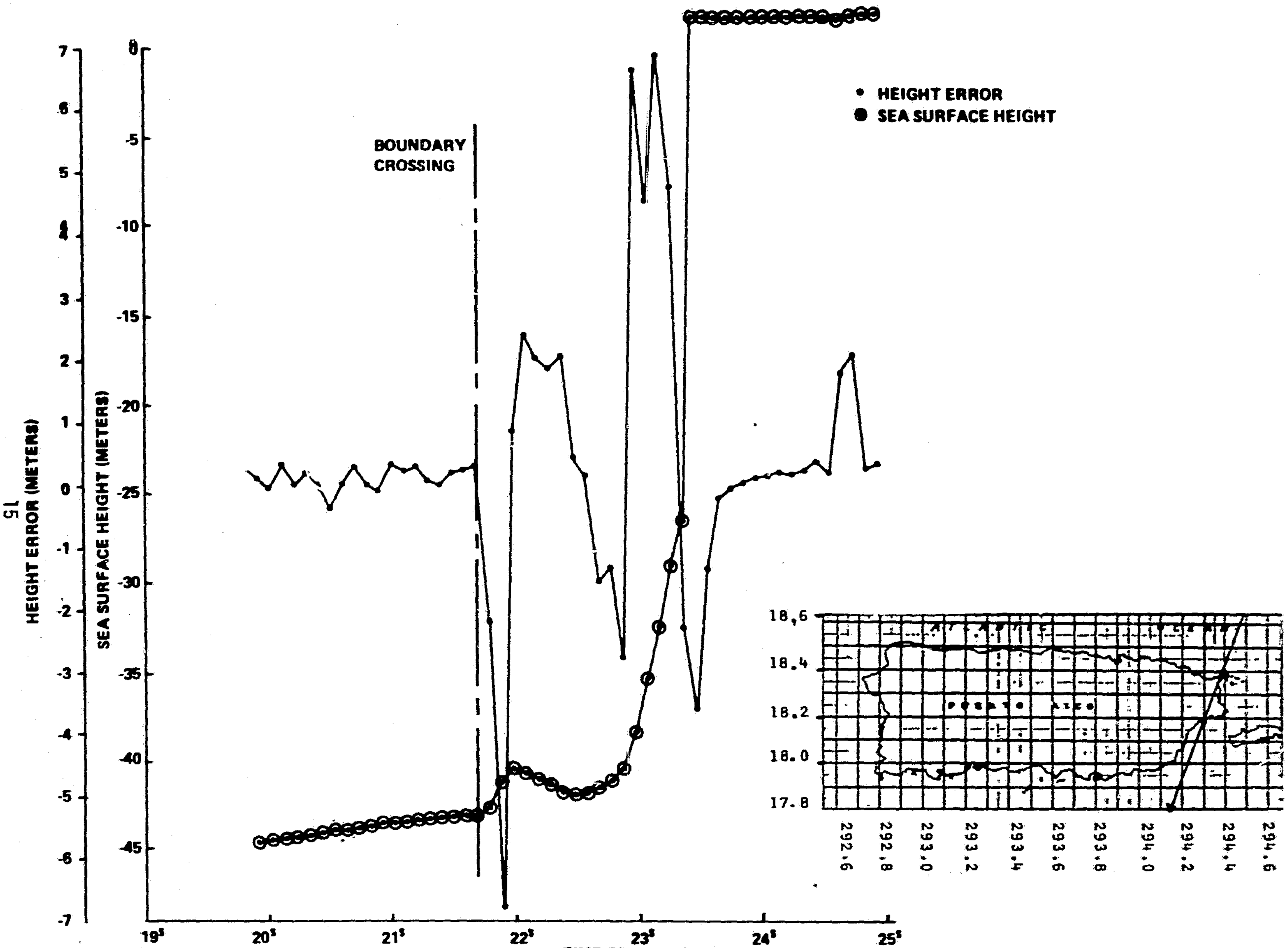


FIGURE 8. SEA SURFACE HEIGHT AND ALTIMETER HEIGHT ERROR FOR SEASAT CROSSING OF PUERTO RICO

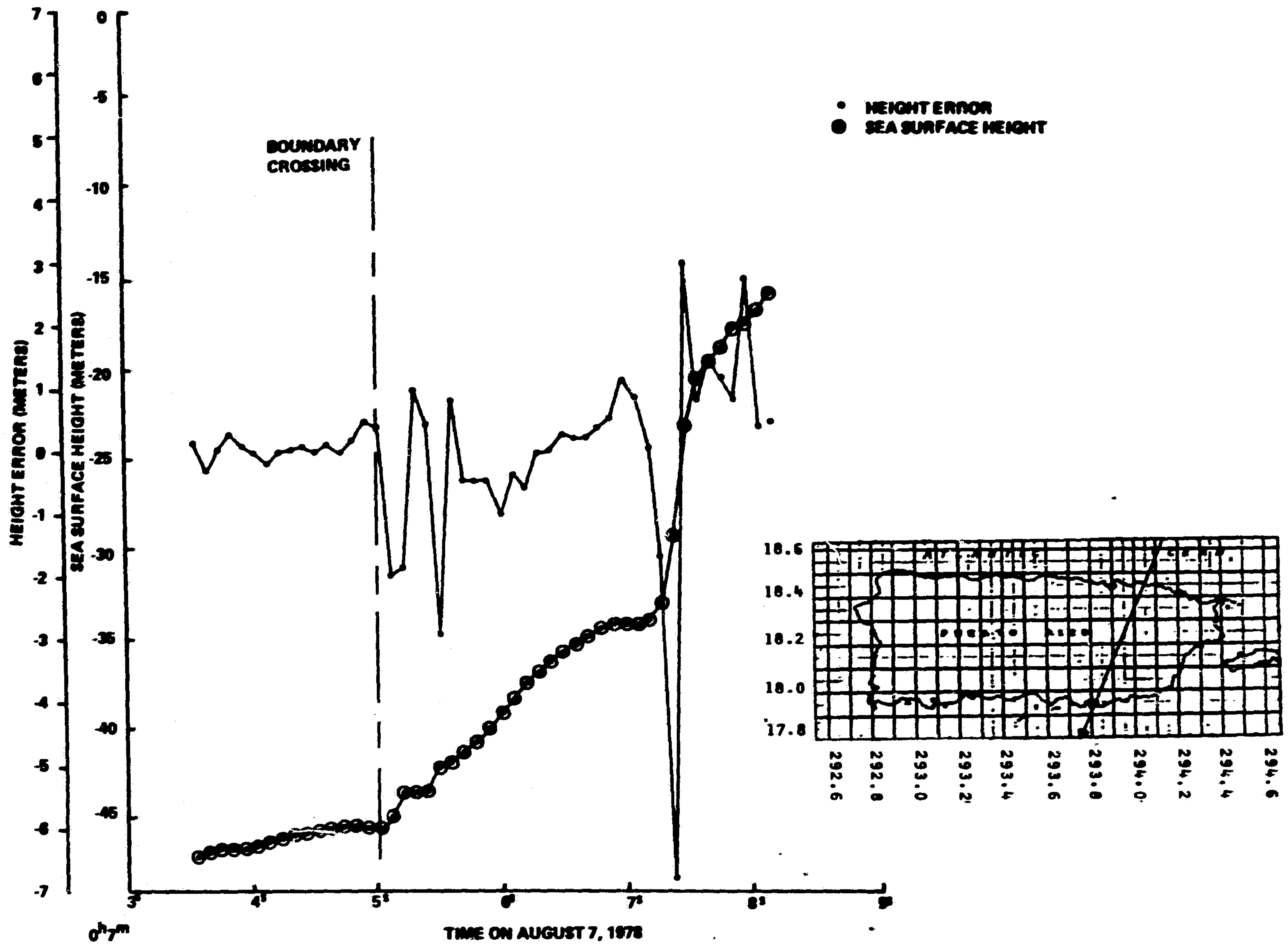


FIGURE 9. SEA SURFACE HEIGHT AND ALTIMETER HEIGHT ERROR FOR SEASAT CROSSING OF PUERTO RICO

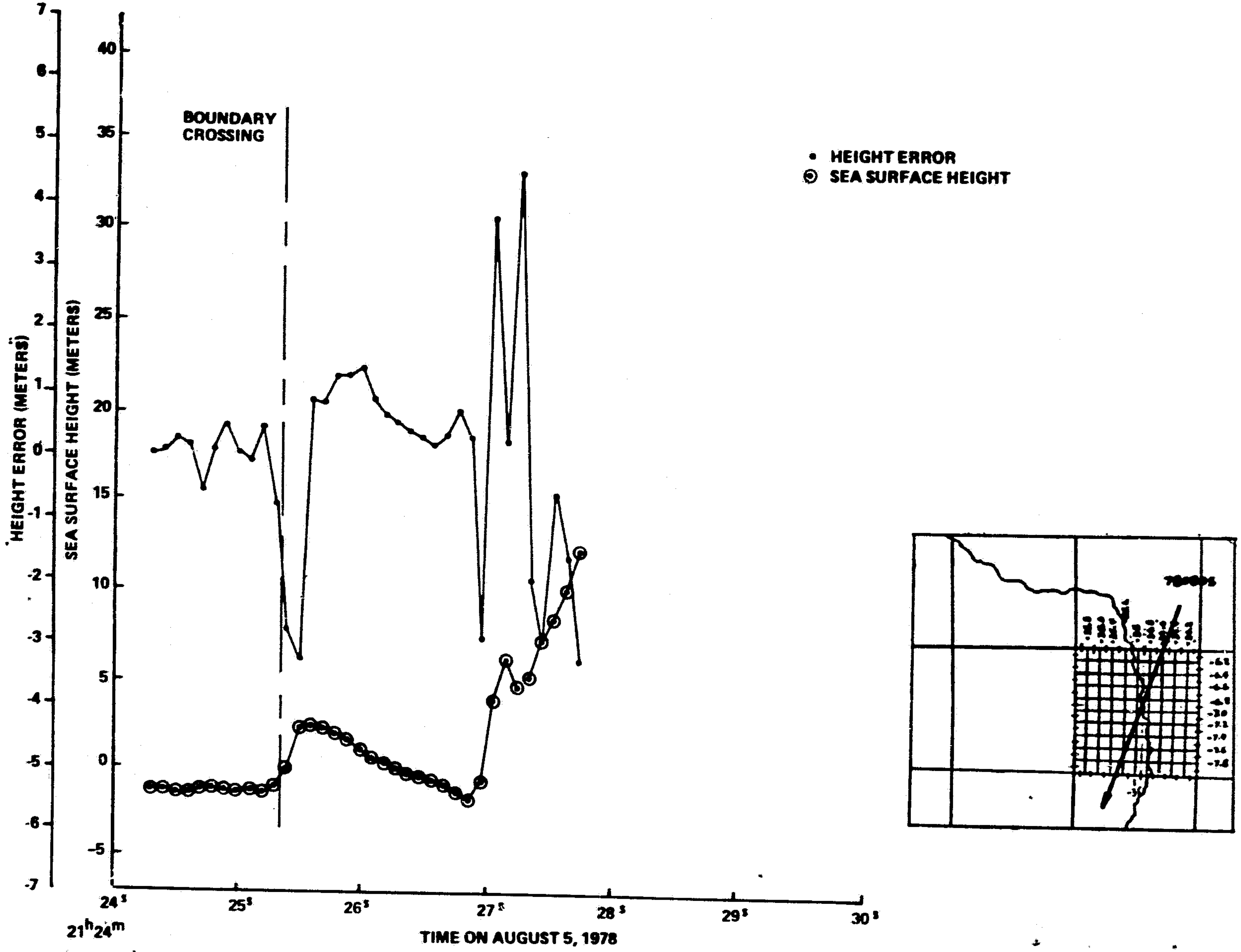


FIGURE 10. SEA SURFACE HEIGHT AND ALTIMETER HEIGHT ERROR FOR SEASAT CROSSING OF SOUTH AMERICA

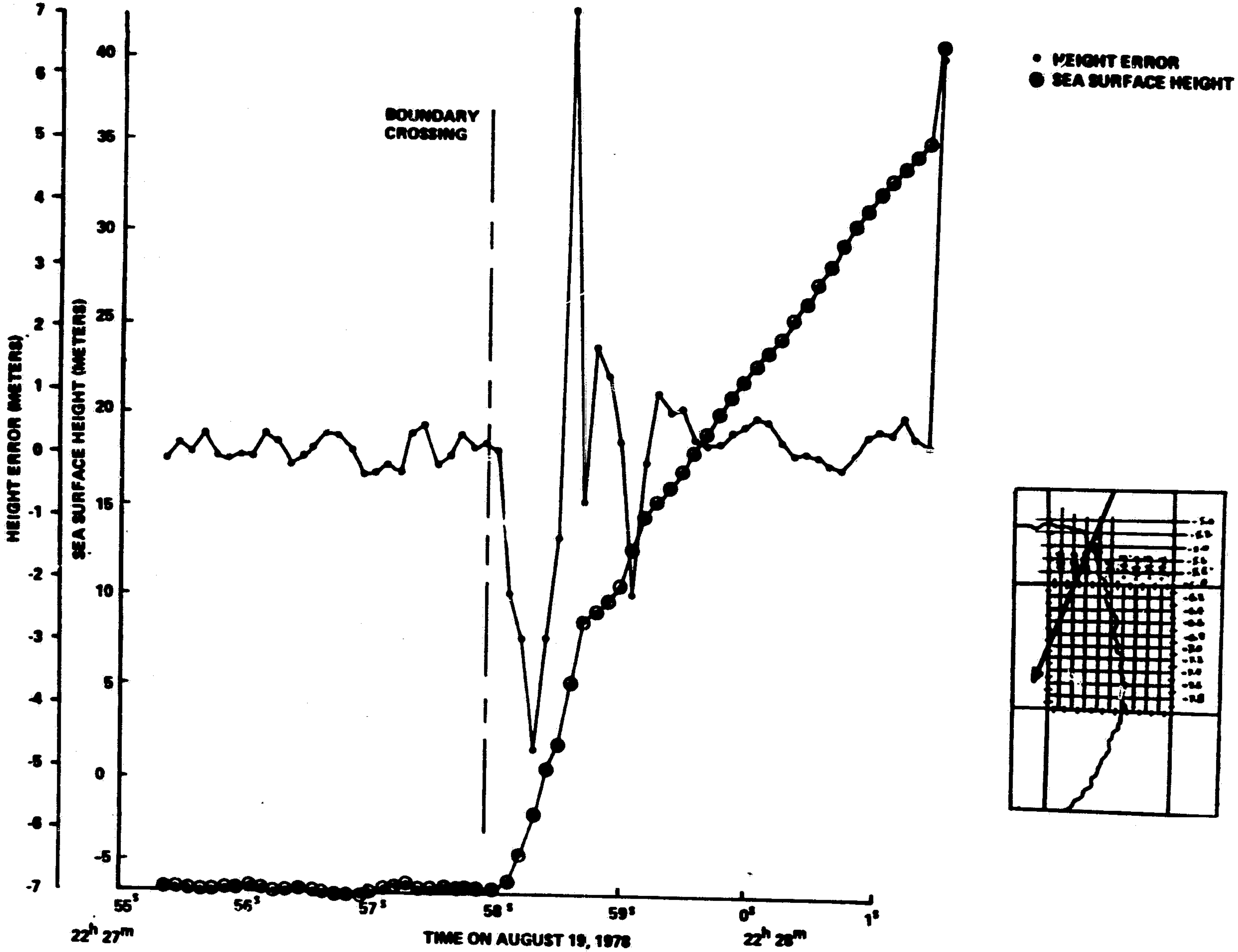


FIGURE 11. SEA SURFACE HEIGHT AND ALTIMETER HEIGHT ERROR FOR SEASAT CROSSING OF SOUTH AMERICA

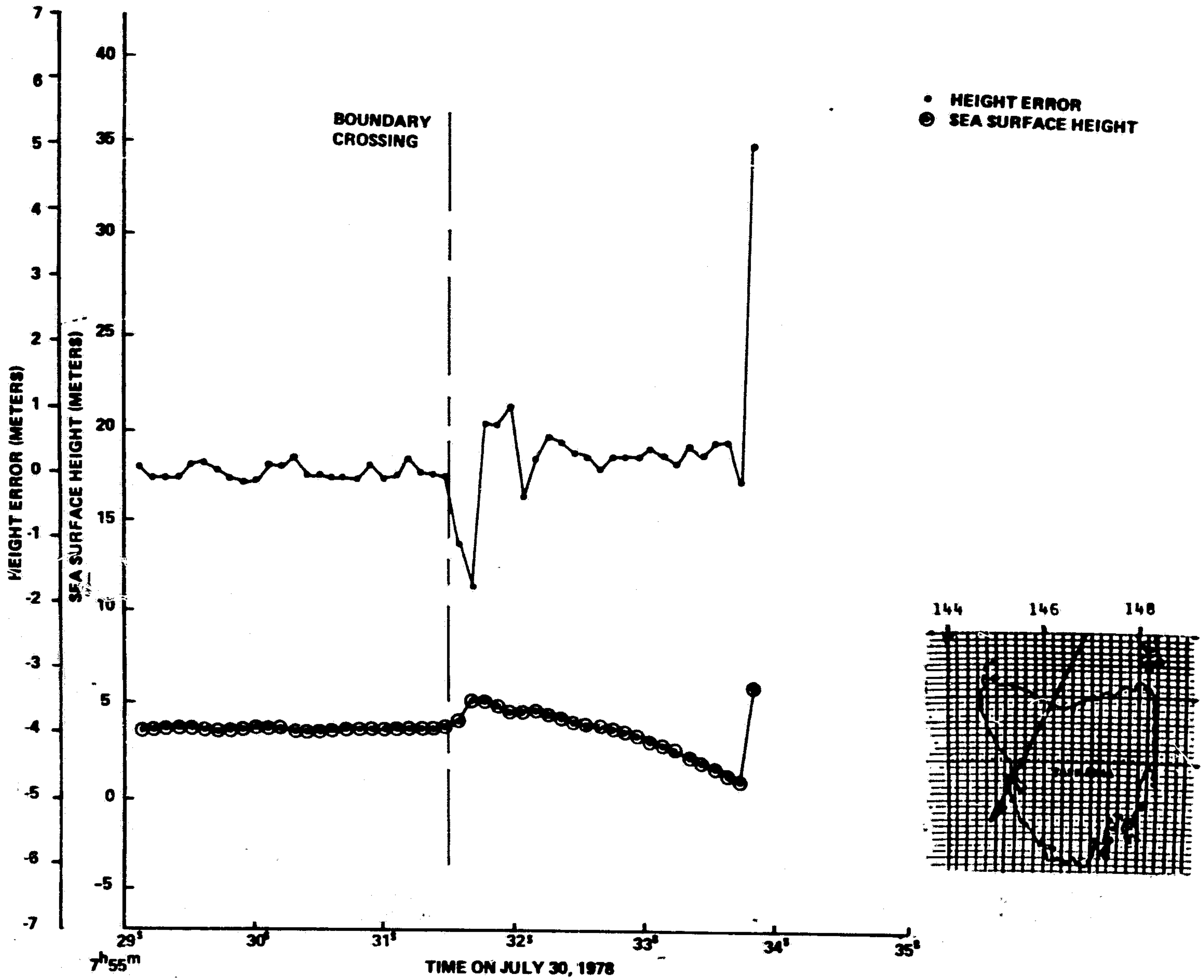


FIGURE 12. SEA SURFACE HEIGHT AND ALTIMETER HEIGHT ERROR FOR SEASAT CROSSING OF TASMANIA

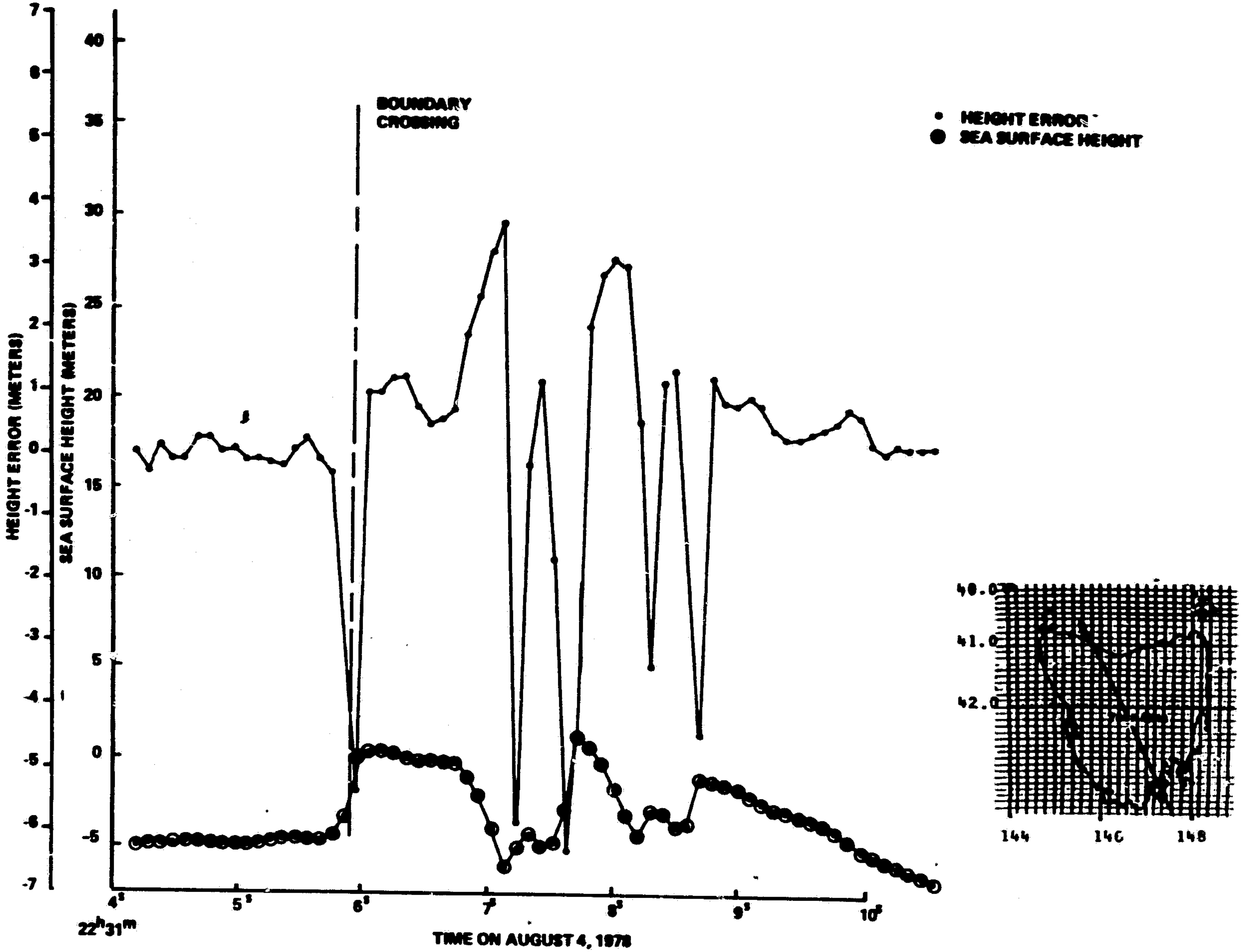


FIGURE 13. SEA SURFACE HEIGHT AND ALTIMETER HEIGHT ERROR FOR SEASAT CROSSING OF TASMANIA

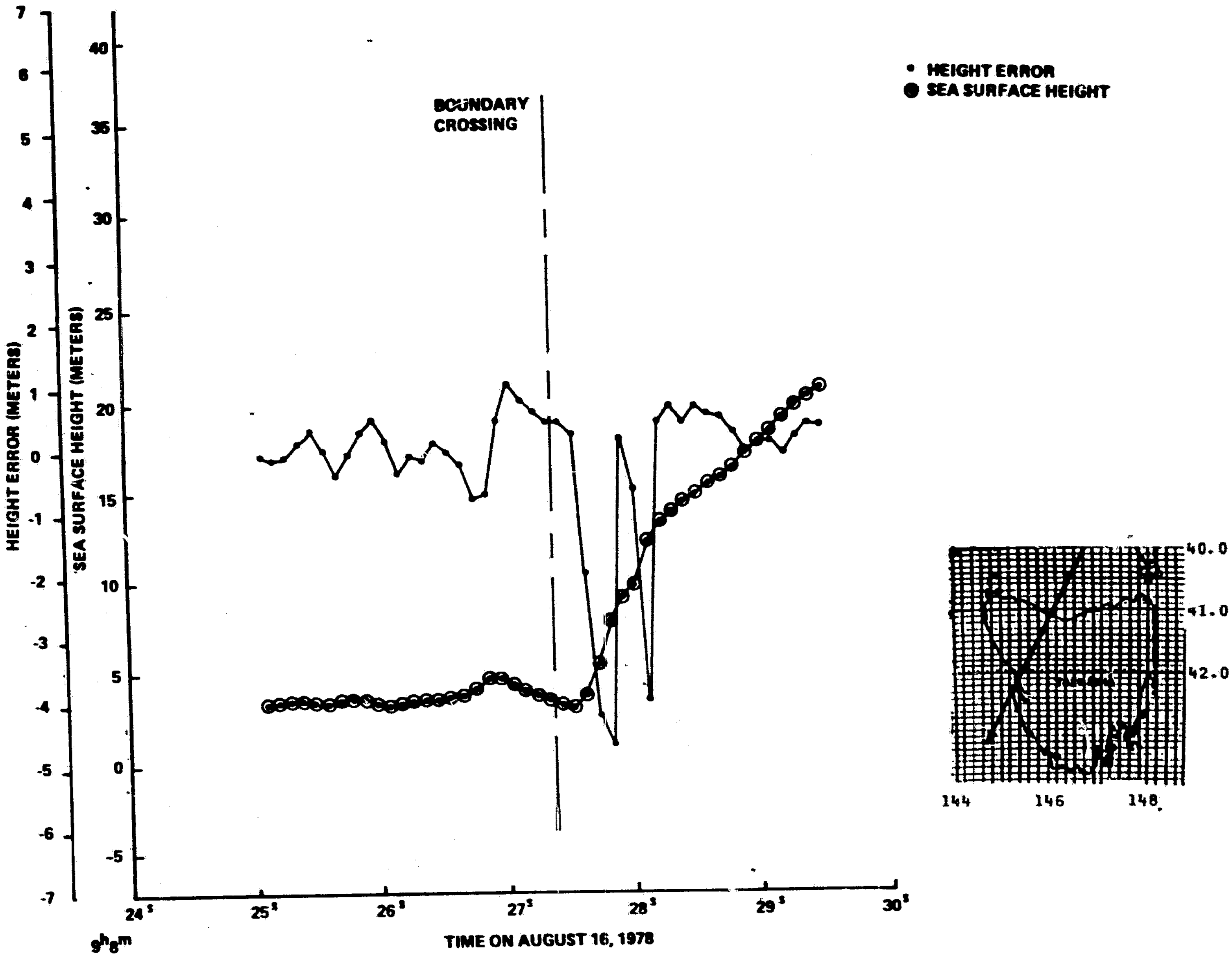


FIGURE 14. SEA SURFACE HEIGHT AND ALTIMETER HEIGHT ERROR FOR SEASAT CROSSING OF TASMANIA

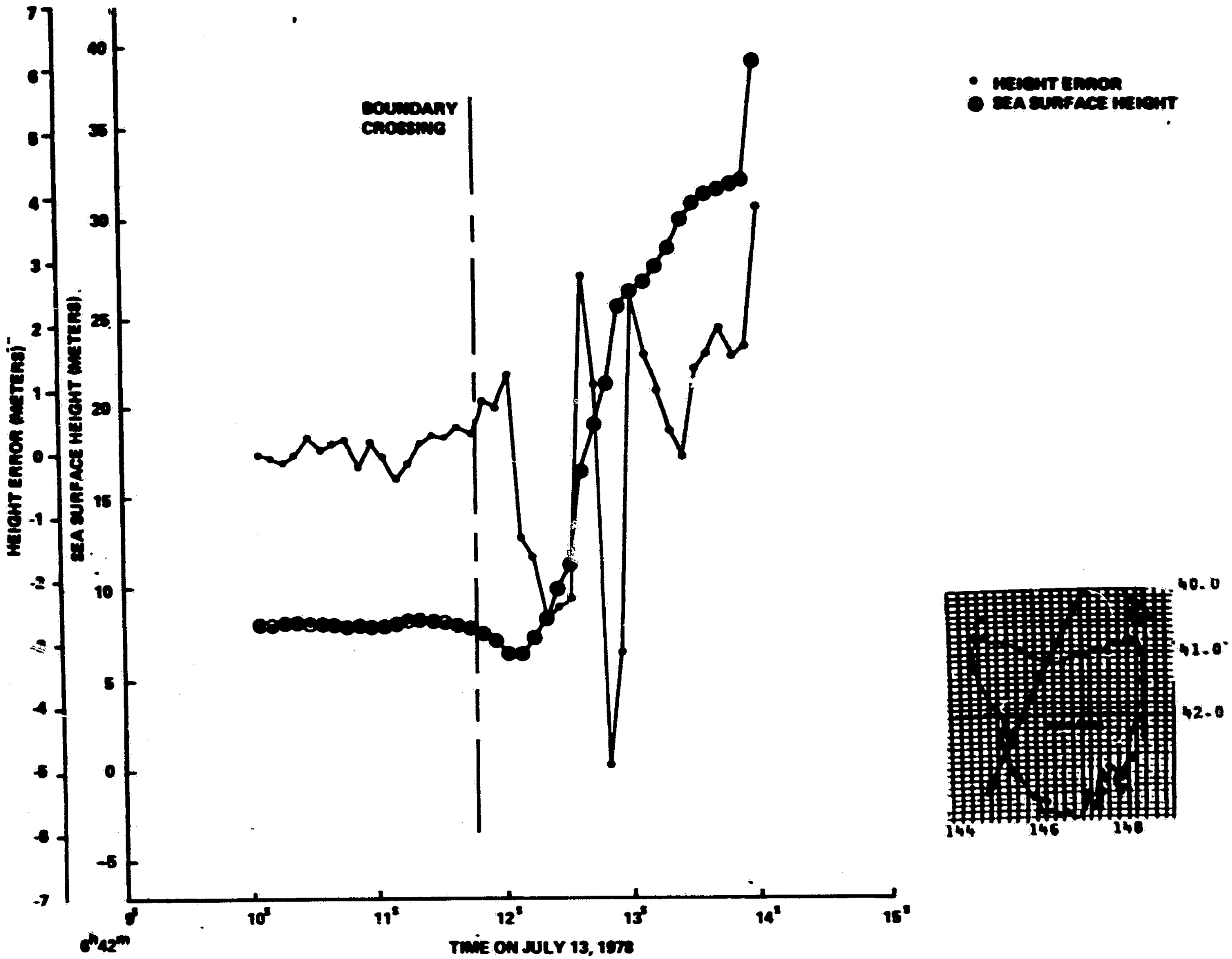


FIGURE 15. SEA SURFACE HEIGHT AND ALTIMETER HEIGHT ERROR FOR SEASAT CROSSING OF TASMANIA

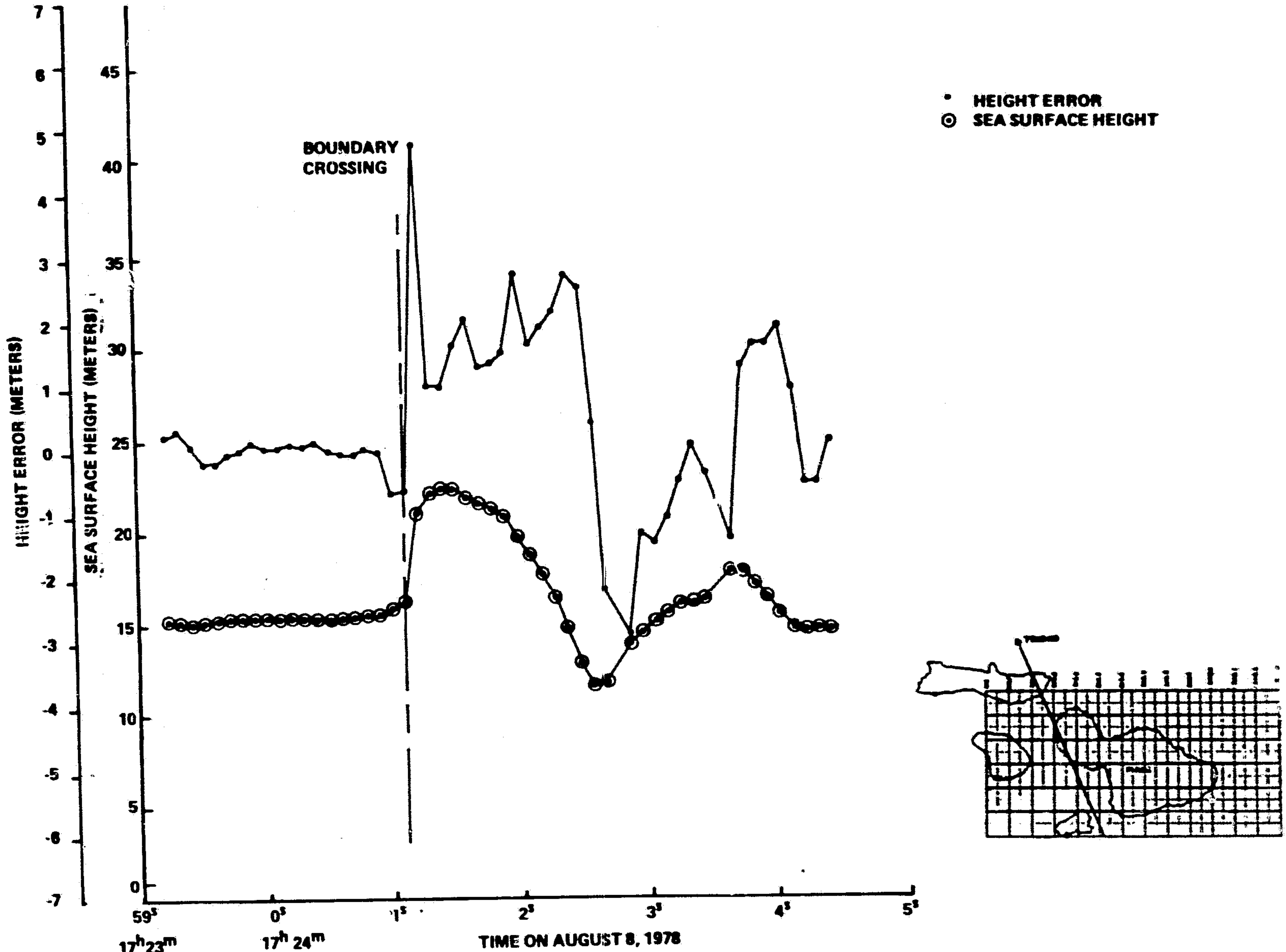


FIGURE 16. SEA SURFACE HEIGHT AND ALTIMETER HEIGHT ERROR FOR SEASAT CROSSING OF MAUI

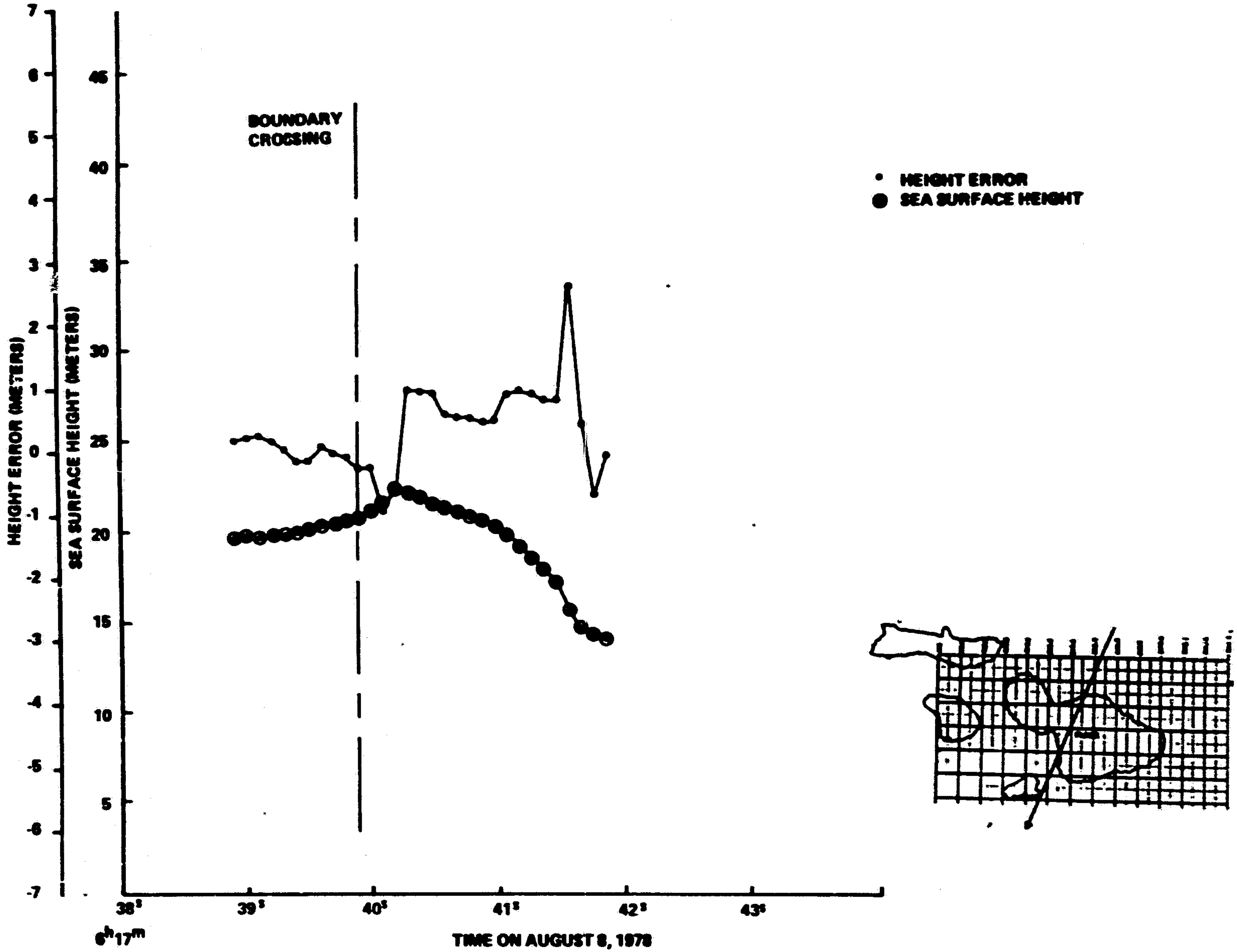


FIGURE 17. SEA SURFACE HEIGHT AND ALTIMETER HEIGHT ERROR FOR SEASAT CROSSING OF MAUI

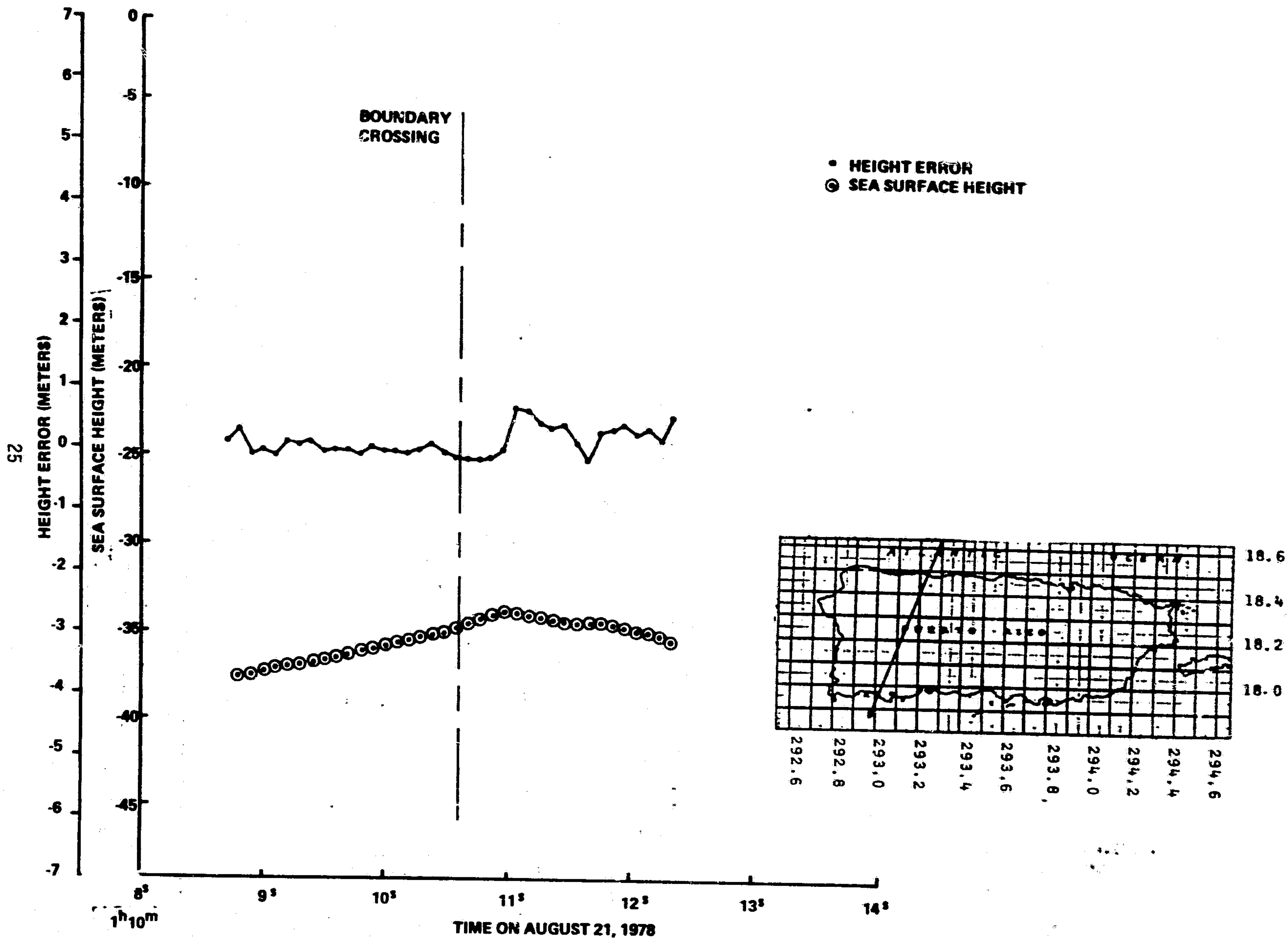


FIGURE 18. SEA SURFACE HEIGHT AND ALTIMETER HEIGHT ERROR FOR SEASAT CROSSING OF PUERTO RICO

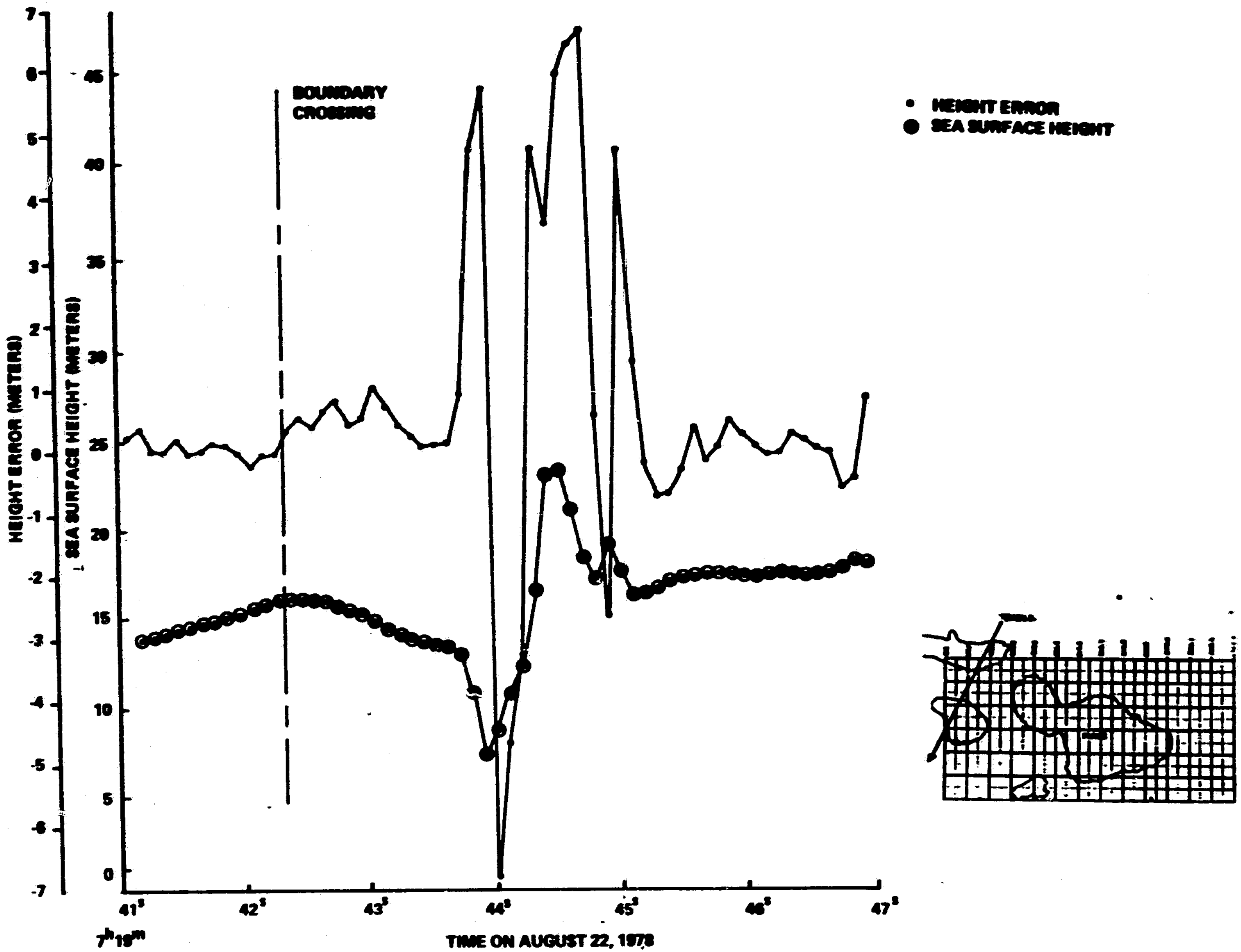


FIGURE 19. SEA SURFACE HEIGHT AND ALTIMETER HEIGHT ERROR FOR SEASAT CROSSING OF MAUI

(Figures 14 - 15), there is also a negative height error with a magnitude greater than 1 m near the boundary crossing, but the negative excursions are preceded by positive excursions having about 1 m magnitude. This behavior is similar to that observed for some of the passes across Bermuda, with the positive height errors having a somewhat larger amplitude.

In Figure 16, which shows the sea surface heights and height errors for crossings of the Maui coastline, there is a negative height error excursion at the boundary crossing, but its amplitude is less than 1 m. There then follows immediately a multi-meter positive excursion in height error. Figure 17, also for a Maui crossing, shows a somewhat similar pattern except that the initial negative height error excursion is almost -1 m, and the subsequent positive excursion is of lower amplitude, only about +1 m.

Finally, Figures 18 and 19 show boundary crossings at Puerto Rico and Maui, respectively, that are anomalous when compared to those crossings discussed above. The height errors recorded near the boundaries are quite small and, in particular, do not reach a negative value close to -1 m. It must be concluded that simple height error could not be used as a good boundary indicator for these passes, or at least not in the sense implied above of looking for the height error to exceed (in magnitude) a number on the order of 1 m. These passes will be considered below in Section 3.3 from the waveform analysis viewpoint.

Table 1 summarizes some of the boundary crossing characteristics that have been extracted from Figures 1 - 19. Basically, this table shows that most of the time a height error in excess of 1 m amplitude is observed very near the actual boundary crossing. Most of the time, this excursion is in the negative direction. However, occasionally this excursion is only positive, and sometimes it does not occur at all.

3.2 Height Errors for Anomalous Ocean Areas

Two types of "anomalous" ocean areas have been investigated to determine the extent to which height errors on the order of 1 m might exist for open ocean regions. The question thus posed was whether a boundary indicator defined by a ± 1 m height error would give a false alarm for certain open ocean conditions.

The first type of open ocean region investigated was the Puerto Rican

GEOGRAPHIC AREA		TIME OF BOUNDARY CROSSING		LARGEST NEGATIVE HEIGHT ERROR NEAR CROSSING		TIME PAST CROSSING AT WHICH ±1 m HEIGHT ERROR OBSERVED	
				VALUE OF HEIGHT ERROR	TIME PAST BOUNDARY CROSSING	-1 m HEIGHT ERROR*	+1 m HEIGHT ERROR*
Bermuda	(Fig. 1)	780913	030207.	-3.75 m	+.1 sec.	+.1 sec.	+.5 sec.
Bermuda	(Fig. 2)	780919	032738.	-4.22 m	+.1 sec.	+.1 sec.	+.3 sec.
Bermuda	(Fig. 3)	780922	030423.	-3.28 m	+.1 sec.	+.1 sec.	+.3 sec.
Bermuda	(Fig. 4)	780925	035309.	-2.34 m	+.2 sec.	+.2 sec.	+.6 sec.
Bermuda	(Fig. 5)	780928	040553.	-3.40 m	+.2 sec.	+.1 sec.	+.5 sec.
Bermuda	(Fig. 6)	781001	041838.	-4.45 m	At Crossing	At Crossing	+.3 sec.
Bermuda	(Fig. 7)	781007	044404.	-3.63 m	+.1 sec.	At Crossing	+.4 sec.
Puerto Rico	(Fig. 8)	780703	214022.	-6.79 m	+.2 sec.	+.1 sec.	+.4 sec.
Puerto Rico	(Fig. 9)	780807	000705.	-2.93 m	+.4 sec.	At Crossing	+.2 sec.(.94m)
South America	(Fig.10)	780805	212425.	-3.28 m	+.1 sec	At Crossing	+.4 sec.
South America	(Fig.11)	780819	222758	-4.68 m	+.2 sec.	At Crossing	+.5 sec.
Tasmania	(Fig.12)	780730	075531.	-1.76 m	+.1 sec.	At Crossing	+.4 sec.
Tasmania	(Fig.13)	780804	223106.	-5.39 m	+.1 sec.	At Crossing	+.4 sec.
Tasmania	(Fig.14)	780816	090827.	-4.68 m	+.2 sec.	At Crossing	-.6 sec.(.99m)
Tasmania	(Fig.15)	780713	064212.	-2.56 m	+.3 sec.	+.1 sec.	At Crossing
Maui	(Fig.16)	780808	172401.	- .73 m	At Crossing	At Crossing(-.73m)	+.1 sec.
Maui	(Fig.17)	780808	061740.	- .94 m	+.1 sec.	+.1 sec.(-.94m)	+.3 sec.(.94m)
Puerto Rico	(Fig.18)	780821	011011.	- .20 m	+.1 sec.	None Below Normal	+.4 sec.(.67m)
Maui	(Fig.19)	780822	071942.	- .29 m	-.3 sec.	None Below Normal	.7 sec(.94m)

* If ±1 m is not reached in vicinity of boundary, value reached is given in parentheses.

TABLE 1. SUMMARY OF CHARACTERISTICS OF SEASAT ALTIMETER HEIGHT ERROR ACROSS OCEAN TO LAND BOUNDARIES

Trench, known to contain geoidal undulations producing the largest accelerations in the Seasat altimeter measurements. However, the altimeter design parameters were such as to allow a maximum 10 cm lag error when crossing the Puerto Rican Trench. Measured height errors over the trench are consistent with this design parameter and are not noticeably different from measured height errors for any other geographic region.

The second type of area investigated was a region of high sea state. Figure 20 shows the sea surface height and height error measured by Seasat during a pass through Hurricane Fico on July 16, 1978. Significant wave heights measured during this pass are shown in Figure 21, and reach some 12 m. Maximum height error during the pass through the hurricane does not reach the 1 m level, but it does come close. This sample is thus not convincing proof that the 1 m level could not be reached during a hurricane. In fact, examination of data for July 16, prior to the pass through Fico, does show a height error exceeding 1 m, with a sea state in the vicinity of 10 m.

It may thus be concluded that high sea state regions may have altimeter height errors on the order of a meter, and that a boundary detection algorithm utilizing height error as a flag must take this into account. However, it should also be noted that one of the major uses of the boundary flag is to indicate that the subsequent data is bad and the altimeter height data across a hurricane such as Fico should be flagged as having errors significantly larger than for normal ocean tracking.

3.3 Water-Land Crossings with Low Height Errors

For two of the crossings listed in Table 1, neither the height error nor the sea surface heights show anomalous behavior in the vicinity of the boundaries. For these two cases, the 10/second waveforms are shown in Figures 22 and 23. For the Puerto Rico boundary crossing, the waveform at the boundary is highly anomalous, with a large peak ahead of the nominal ramp. After this point, the waveform shows a strong degradation from the over ocean shape, particularly with regard to the slope of the plateau region.

For the Maui crossing (Figure 23), the waveform at the boundary, and for a couple of points past the boundary, do not show characteristics that are discernably different from the over ocean shapes. Beyond these times, however, the waveforms show deterioration similar to that observed in Figure 22 for the Puerto Rico boundary crossing, with the plateau region

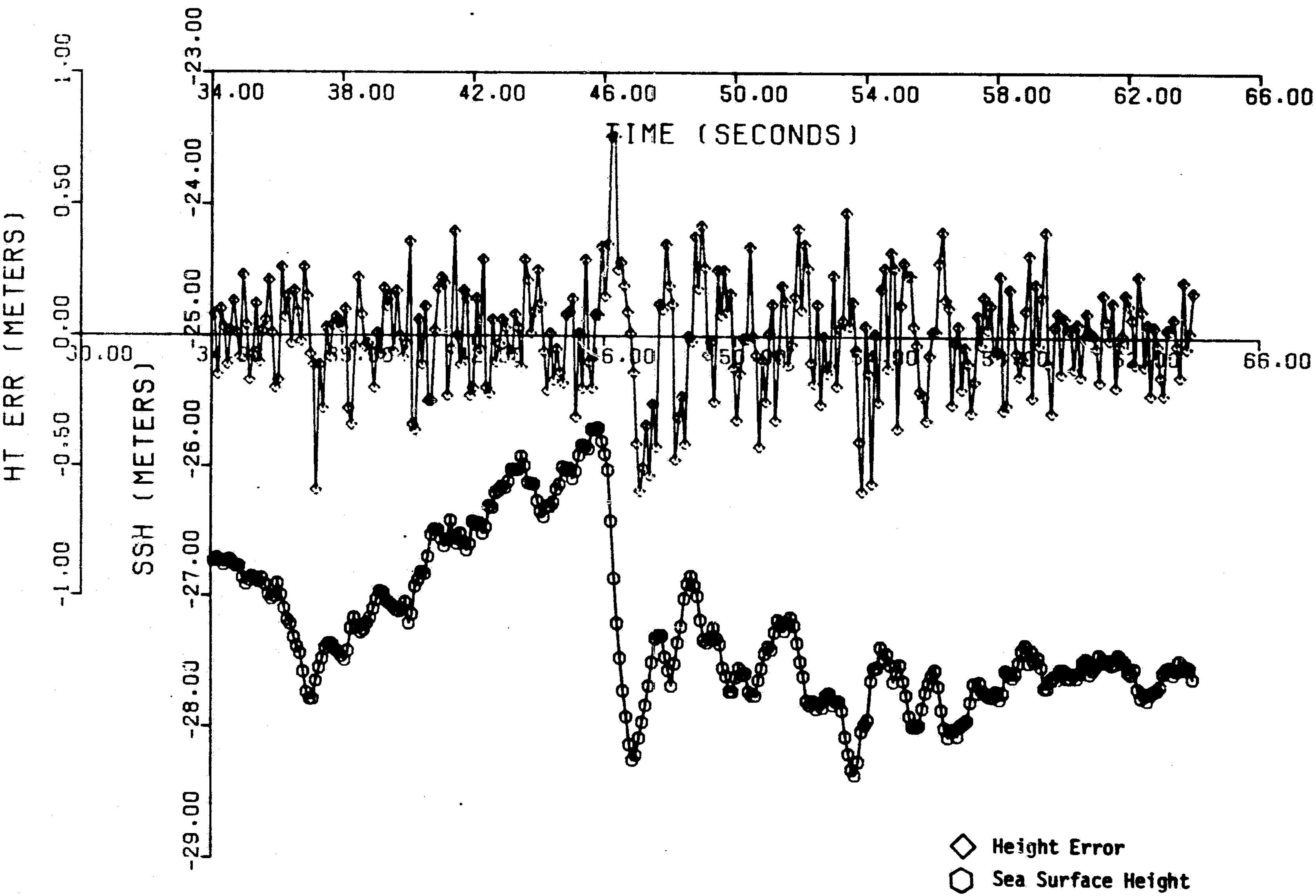


Figure 20. Sea Surface Height and Height Error Across Hurricane Fico on July 16, 1978.

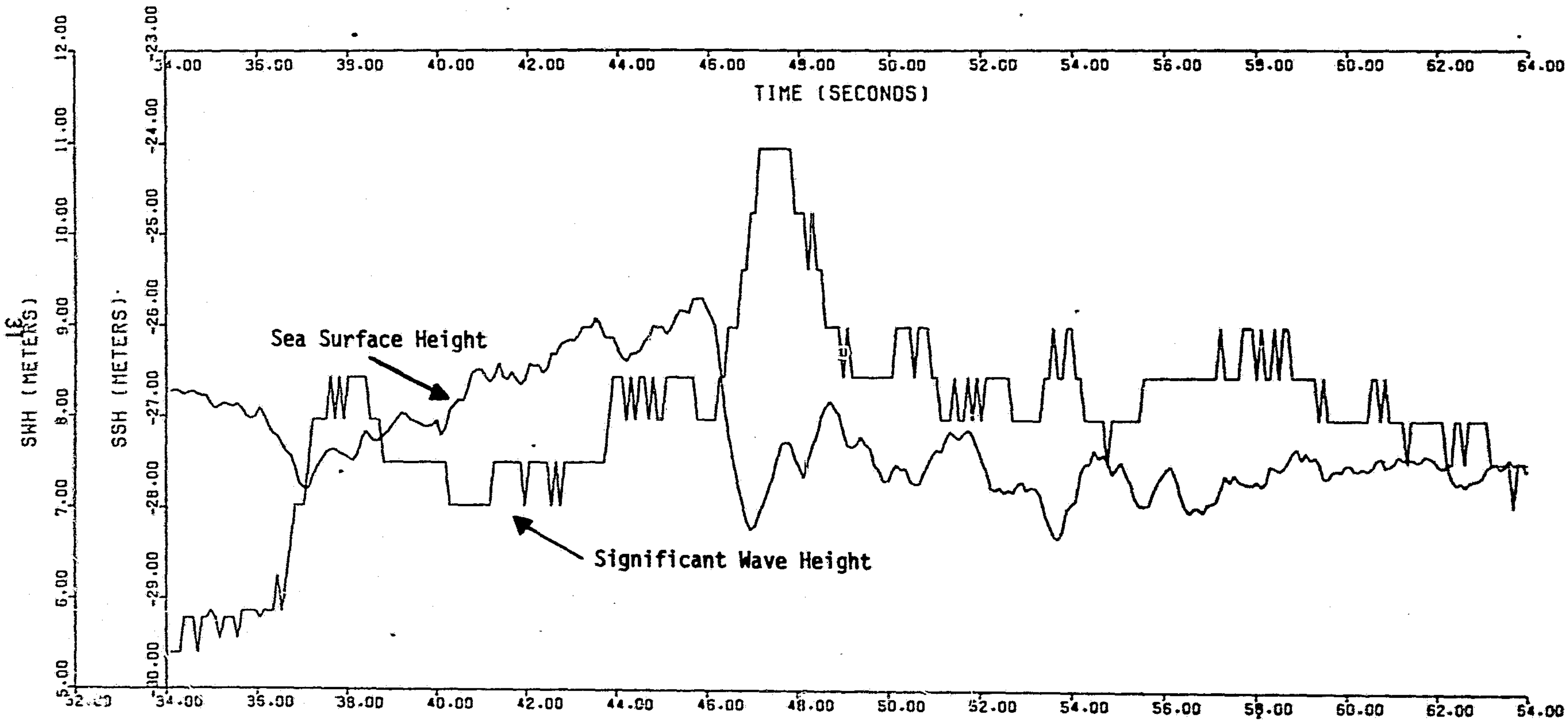


Figure 21. Sea State and Sea Surface Height Across Hur·icane Fico on July 16, 1978.

Figure 22. Instantaneous (0.1 second average) Seasat Altimeter Waveforms Near Puerto Rico Boundary Crossing on August 21, 1978.

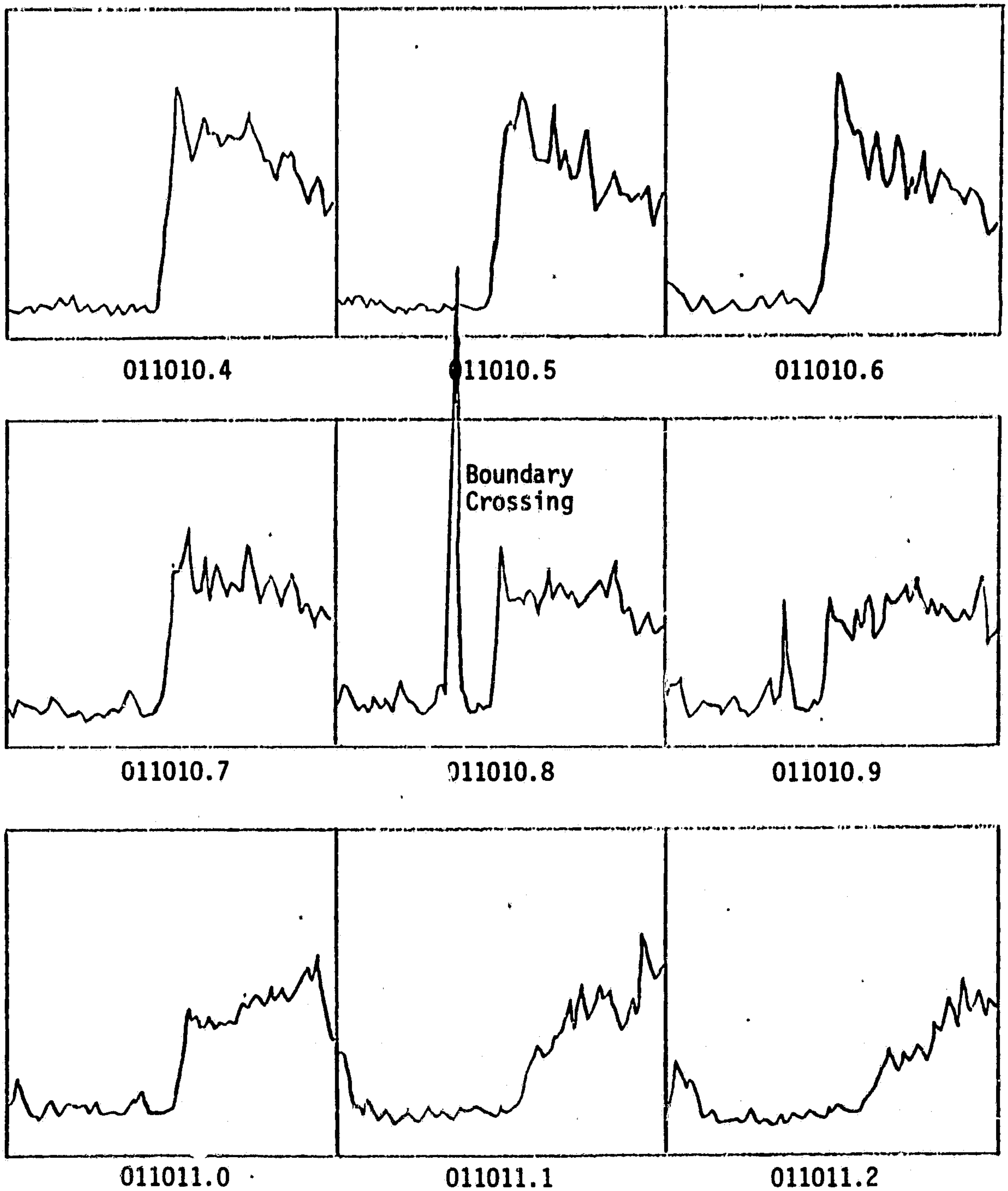
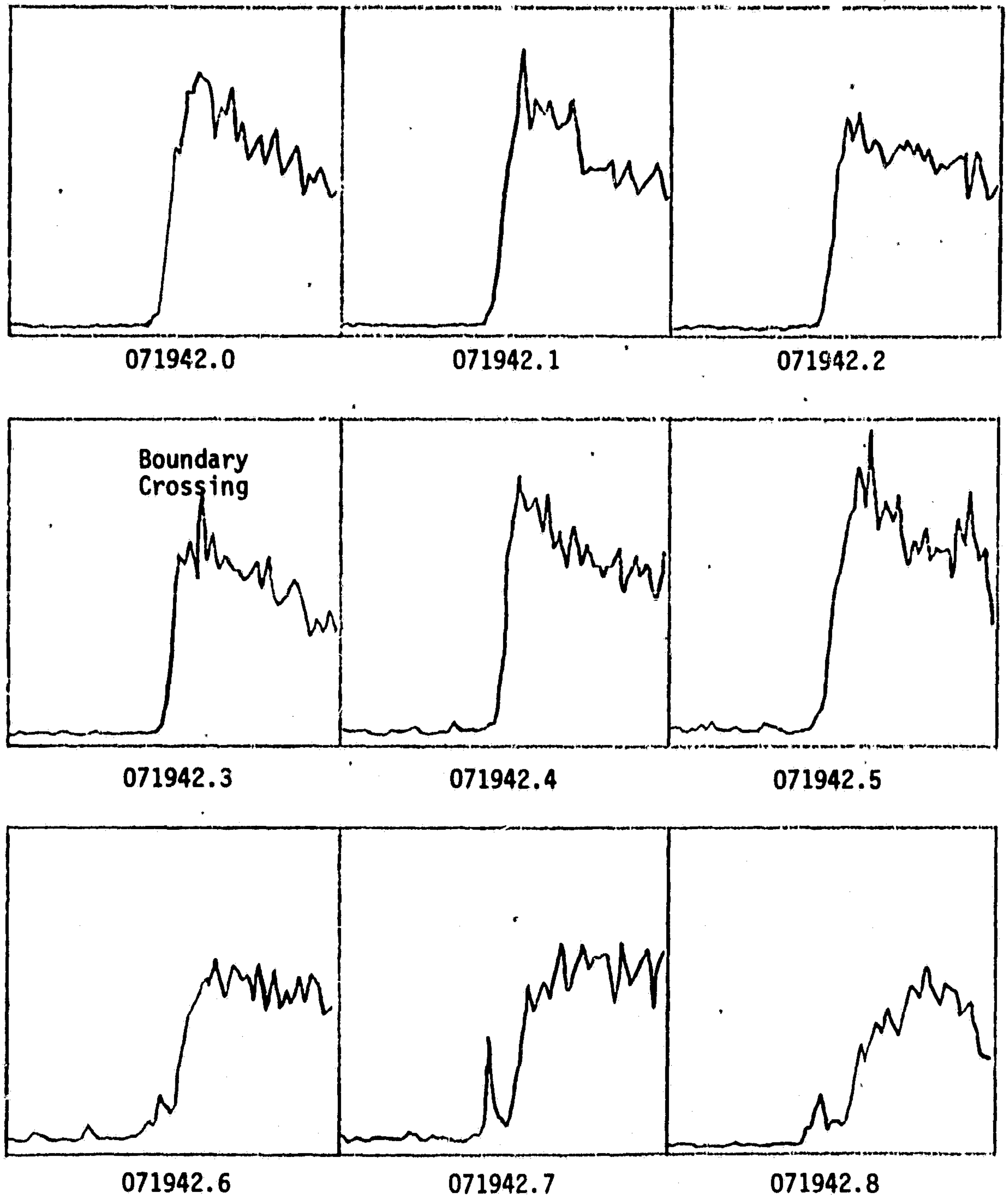


Figure 23. Instantaneous (0.1 second average) Seasat Altimeter Waveforms Near Maui Boundary on August 22, 1978.



first showing a flat and then a rising shape.

It thus appears that a boundary crossing may be detected by the shape of the return waveform, but the distorted shape may be several tenths of a second past the boundary. Assuming that the final editing algorithm leads to the deletion of data a half second or more prior to the detected boundary, this late detection would not really pose a problem.

A question which now arises, however, is the following: If boundaries are not reliably detected by height error, and waveform shapes must be analyzed, does the height error provide additional useful information? The answer, of course, depends upon the sophistication of the waveform analysis, since height error can be one of the parameters determined from the waveform analysis.

3.4 Boundary Detection Based on Return Pulse Trailing Edge Analysis

The trailing edge of the Seasat altimeter return pulse was analyzed for some of the crossings discussed above. Gates 46-63 were first gain corrected [Hayne, 1981] and then fitted to a straight line. The slope of the line and the rms data fit about the line were computed each 0.098 second for approximately 4 seconds around the boundary crossing time. The choice of a straight line was based on the observation that the normal ocean return for these gates is rather closely approximated by a straight line, as is demonstrated in Figures 22 and 23. Further, in the vicinity of the boundary, due to finite footprint size,

- The trailing edge will begin to include return beyond the boundary about one second prior to crossing of the boundary by the subsatellite track. The beyond boundary return may be stronger, weaker, or not noticeably different than the normal ocean returns.
- After boundary crossing, the return pulse shape may be drastically different than the normal ocean return. For ice or flat land, the trailing edge dropoff may be much sharper than normal. For irregular terrain, irregularly shaped return pulses may be expected, as shown by the last several waveforms in both Figures 22 and 23.

Based on this rationale, large variations in trailing edge slope would be expected around a boundary, and the straight line approximation may also not be very good, so that the rms of fit would also significantly increase. In practice, the (0.1 second) sample to sample variation in the rms of fit to the normal ocean return pulse makes identification of increased noise levels at the boundary difficult, and this potential indicator will be discarded for this reason. The trailing edge slopes for some of the crossings discussed above are shown in Figures 24-30 and will be briefly discussed.

Of primary interest is the question of whether the trailing edge test can detect the boundaries missed by the height error test. Figure 24 shows the trailing edge slope for the August 22 crossing onto Maui for which the height error was shown in Figure 19 and the waveform plots in Figure 23. The slopes do show slight perturbations about 1 second prior to land crossing, as might be expected. The perturbations are not, however, of sufficient magnitude to make them readily distinguishable from the normal variations in the return pulse slopes. It is approximately 0.5 second past the boundary before clearly abnormal slopes occur. For this sample, it is thus evident that the trailing edge slope is not providing boundary crossing indications that are not also being given by the height error.

Figures 25-30 show the trailing edge slopes for other passes from ocean to land. Figure 25 for a Puerto Rico crossing shows a large amplitude positive slope just prior to boundary crossing, followed by a large amplitude negative slope. Figure 26 for another Puerto Rico crossing and Figure 27 for a Tasmania crossing show large negative slopes in the boundary vicinity without the preceding large positive slope. Figure 28 for another Tasmania crossing also shows the large negative slope after the boundary crossing, with a slightly anomalous positive slope prior to the crossing. Figures 29-30 for two Maui boundary crossings show relatively large negative slopes about 0.5 second prior to the boundary crossing, but the excursions only marginally exceed the noise level.

Based on these results, it would have to be concluded that the trailing edge slope is not a leading candidate for a boundary detector, with the probability of boundary detection not significantly enhanced by including its usage along with the height error detector.

FIGURE 24. WAVEFORM TRAILING EDGE SLOPE NEAR OCEAN–LAND BOUNDARY CROSSING ONTO MAUI ON AUGUST 22, 1978

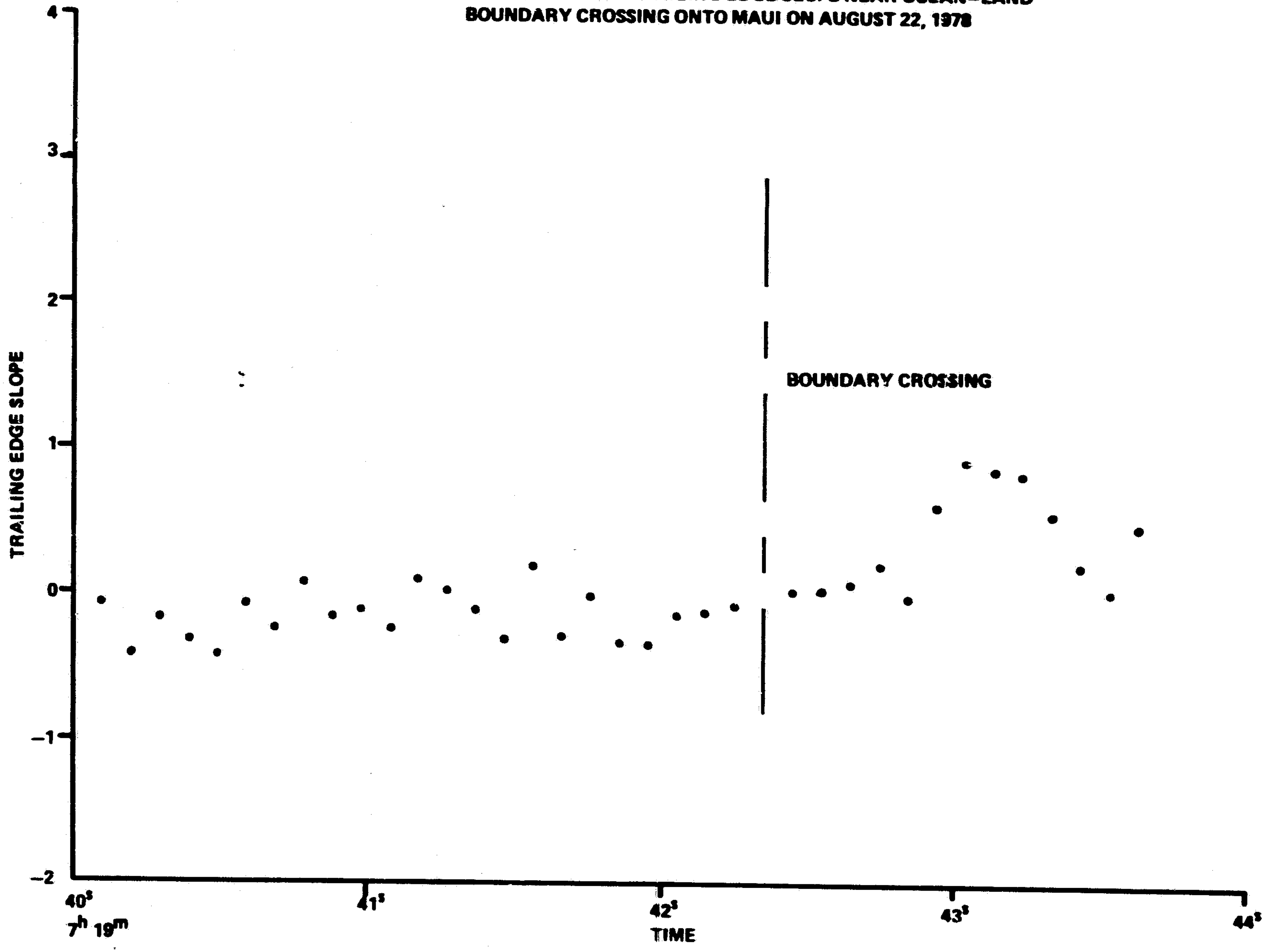


FIGURE 25. WAVEFORM TRAILING EDGE SLOPE NEAR OCEAN–LAND BOUNDARY CROSSING ONTO PUERTO RICO ON AUGUST 7, 1978

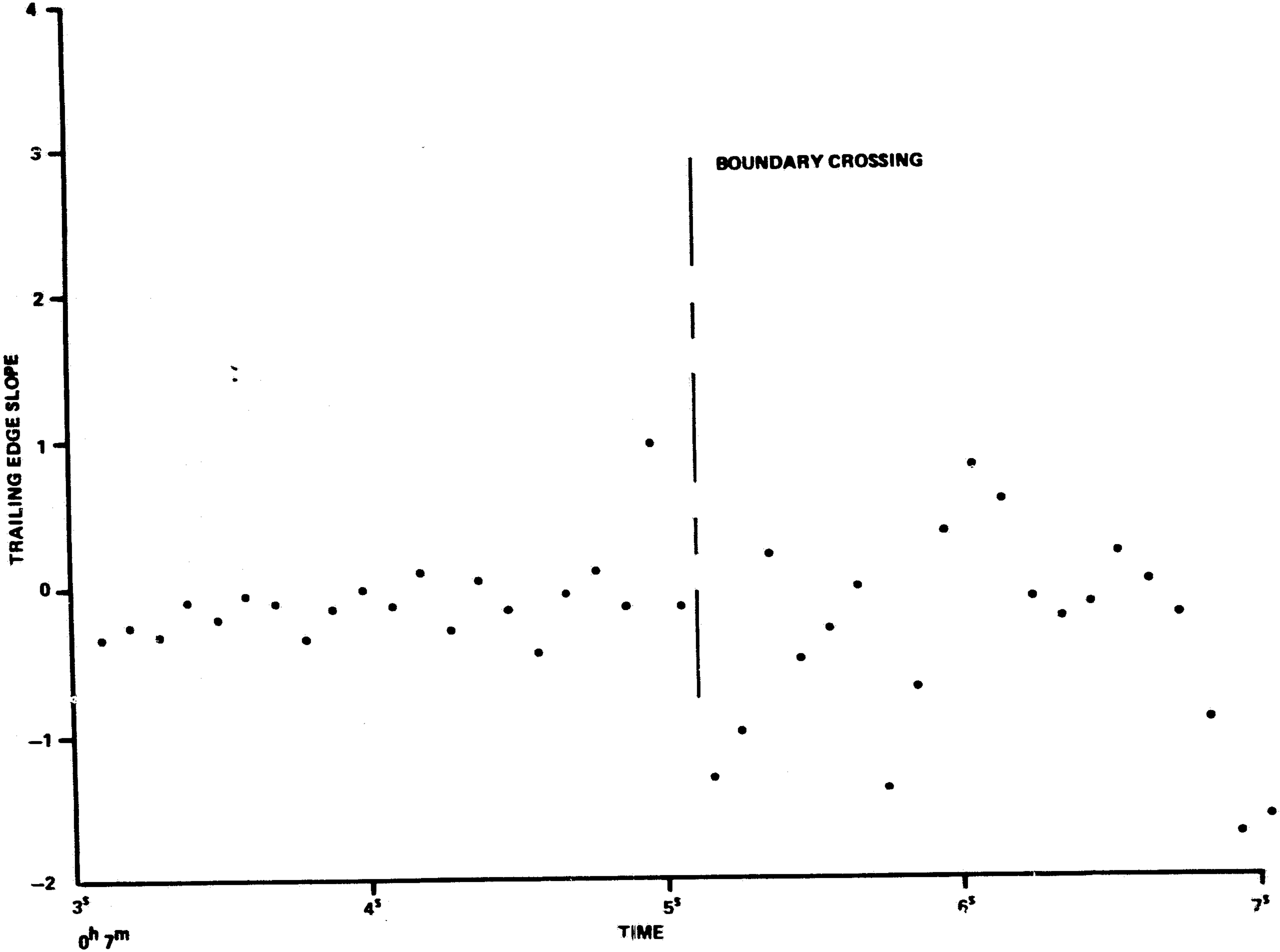


FIGURE 23. WAVEFORM TRAILING EDGE SLOPE NEAR OCEAN–LAND BOUNDARY CROSSING ONTO PUERTO RICO ON JULY 3, 1978

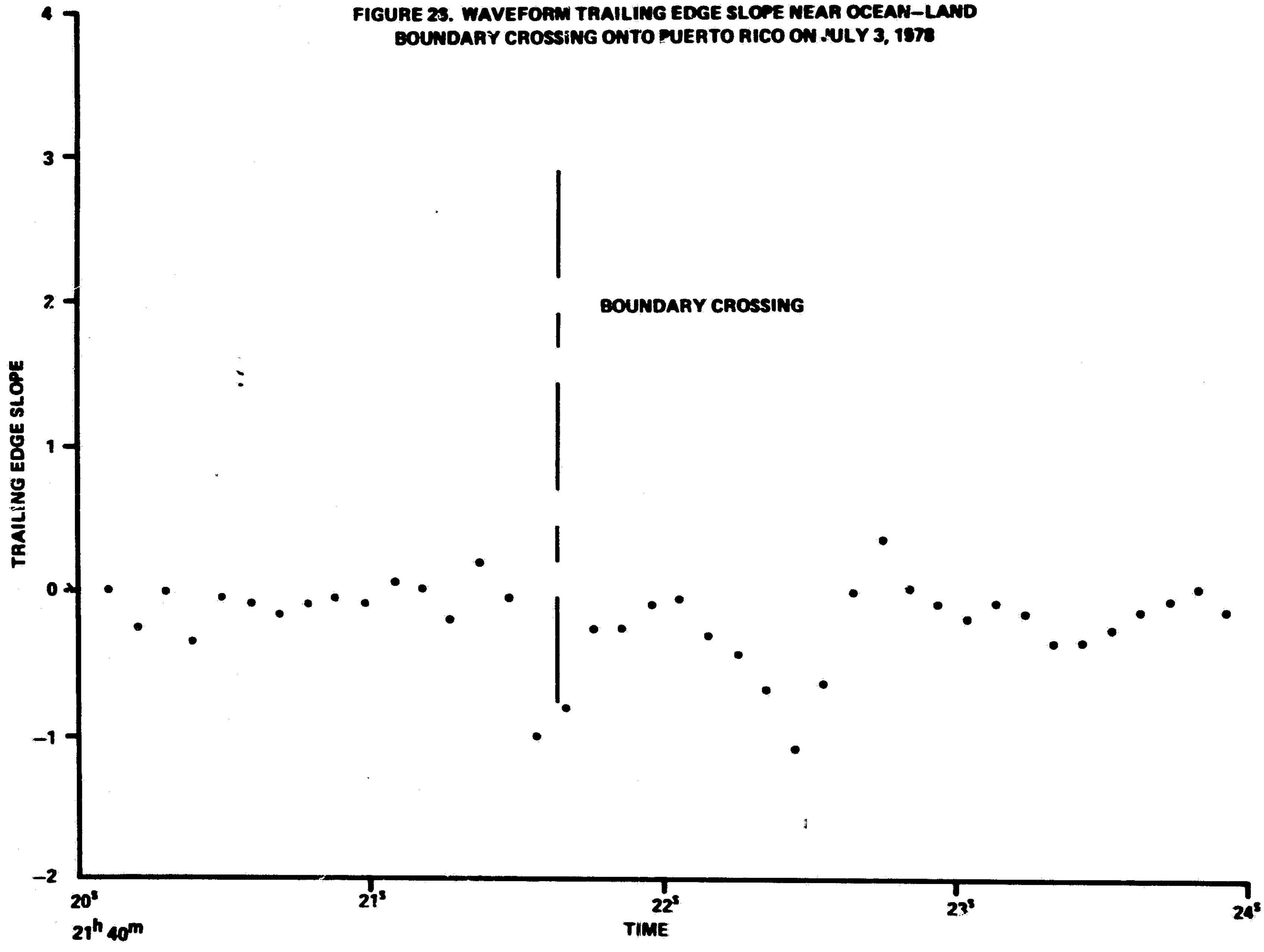


FIGURE 27. WAVEFORM TRAILING EDGE SLOPE NEAR OCEAN–LAND BOUNDARY CROSSING ONTO TASMANIA ON AUGUST 4, 1978

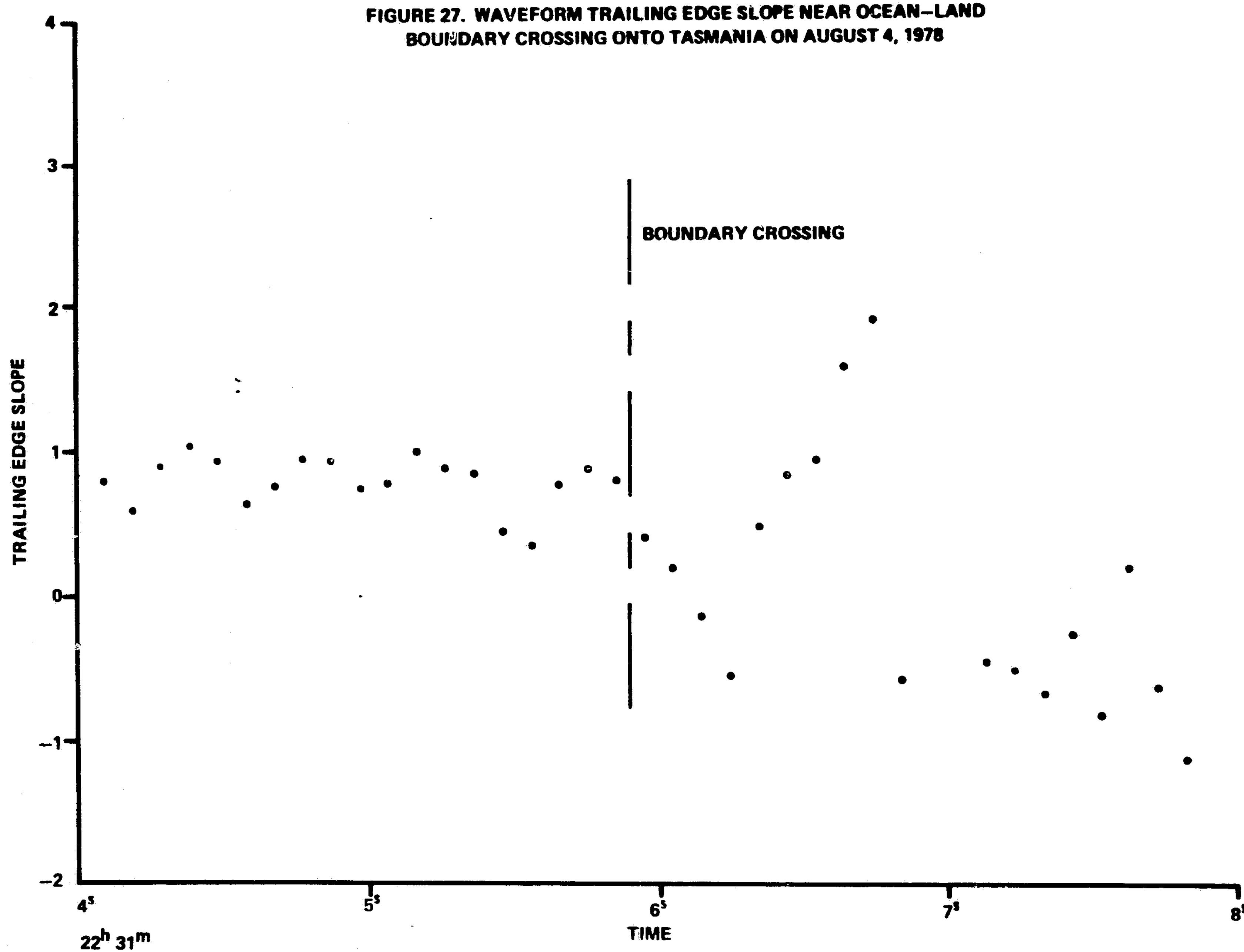


FIGURE 28. WAVEFORM TRAILING EDGE SLOPE NEAR OCEAN–LAND BOUNDARY CROSSING ONTO TASMANIA ON JULY 13, 1978

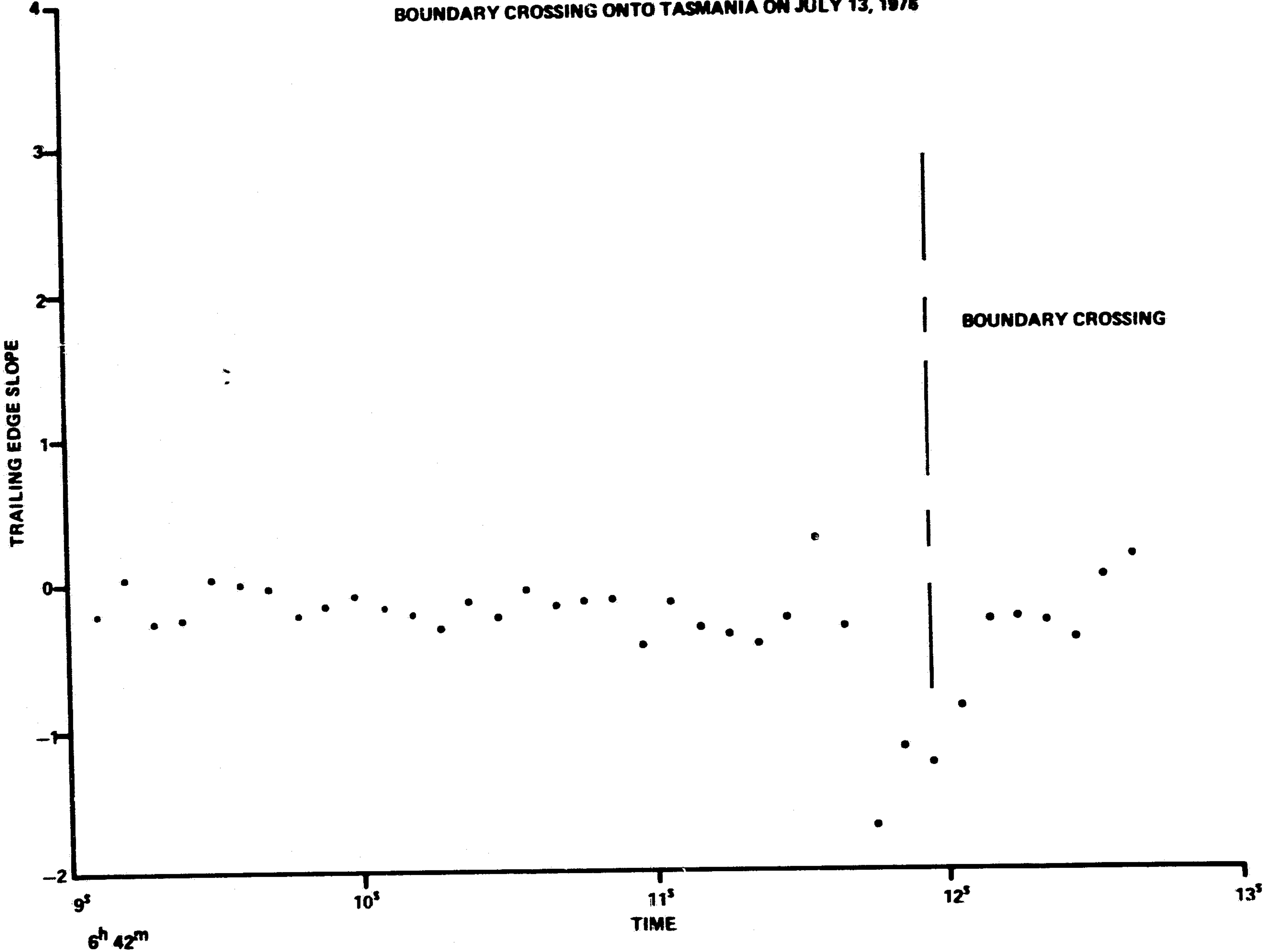


FIGURE 29. WAVEFORM TRAILING EDGE SLOPE NEAR OCEAN–LAND BOUNDARY CROSSING ONTO MAUI ON AUGUST 8, 1978

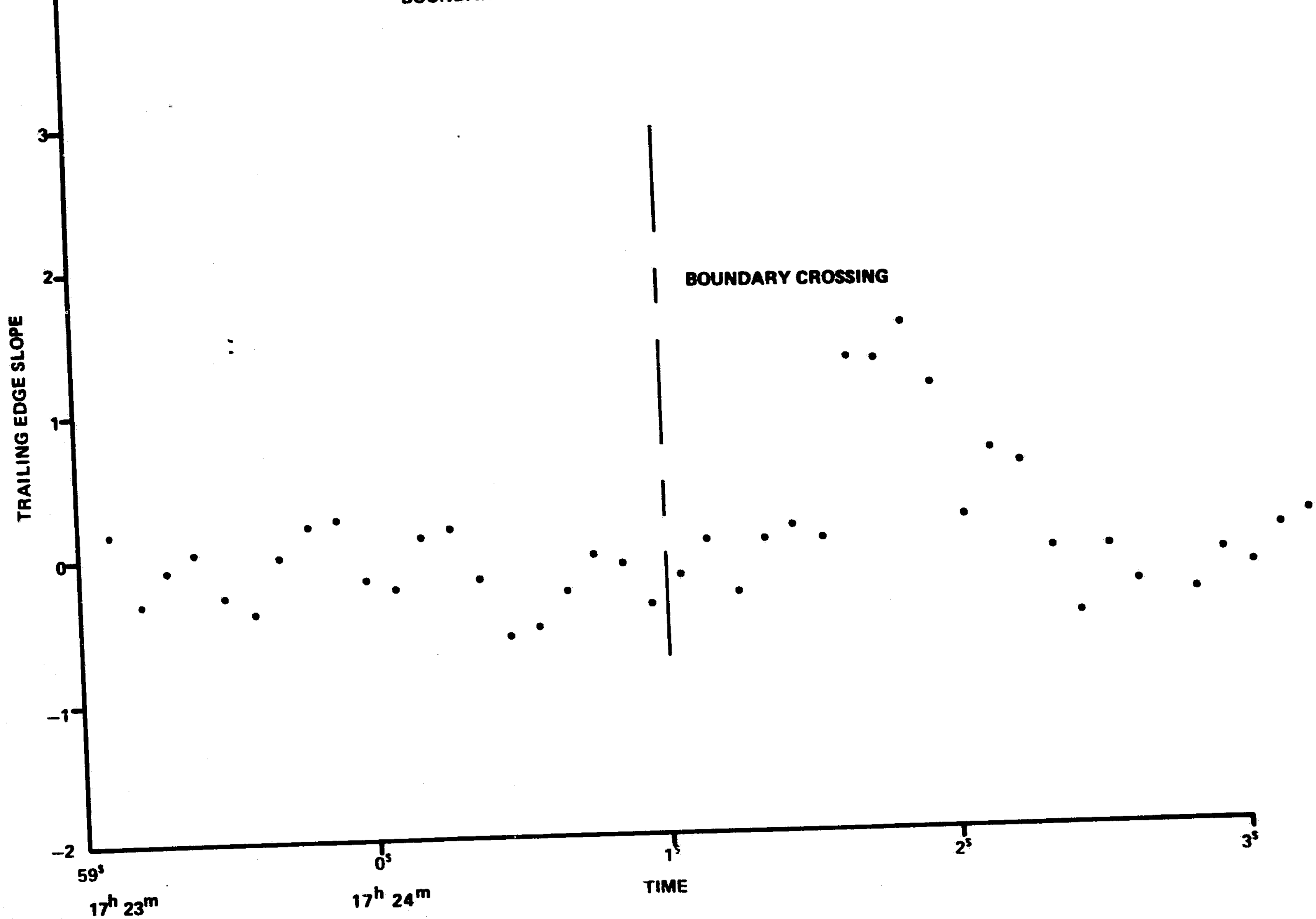
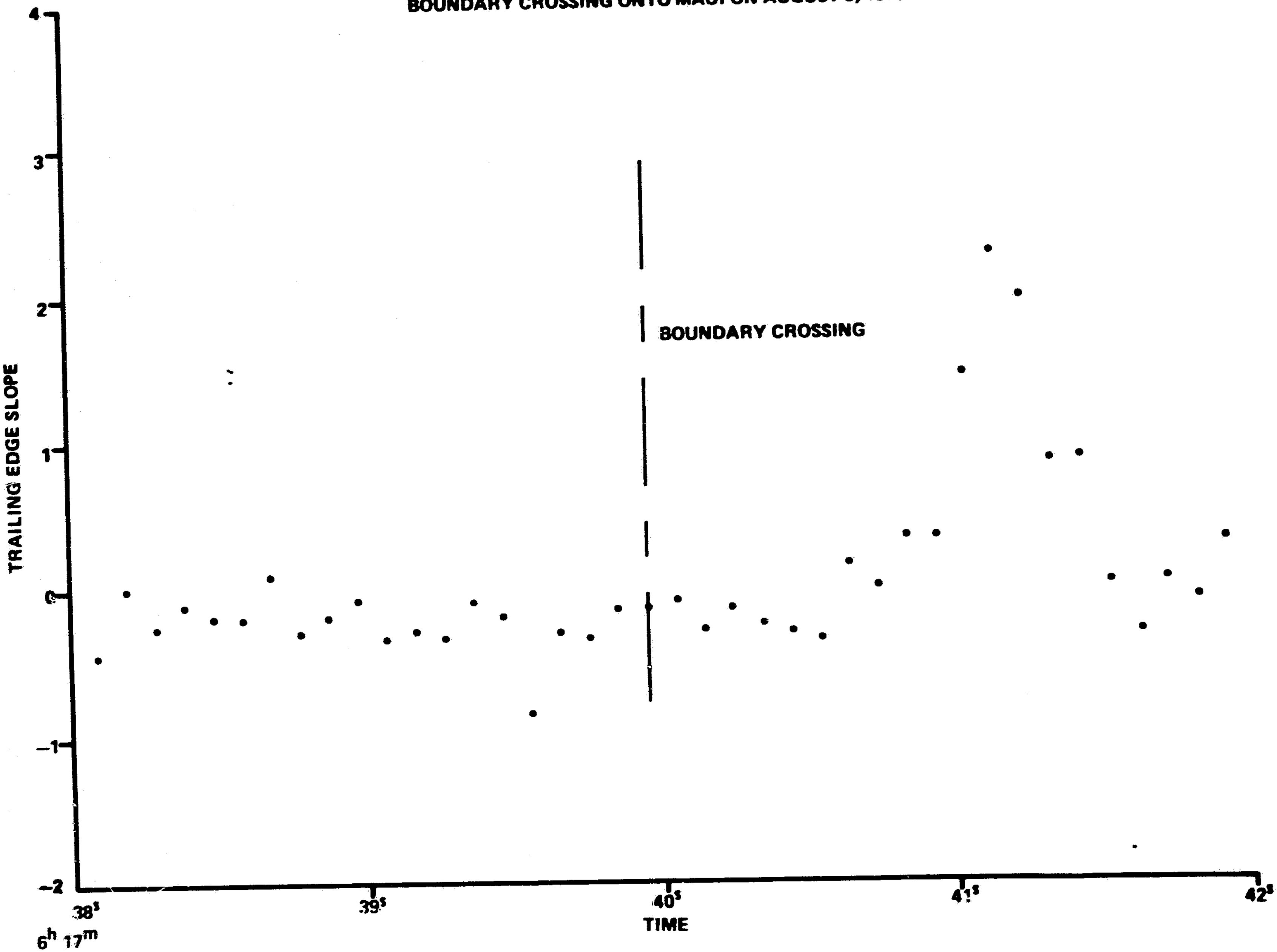


FIGURE 30. WAVEFORM TRAILING EDGE SLOPE NEAR OCEAN—LAND BOUNDARY CROSSING ONTO MAUI ON AUGUST 8, 1978



Section 4.0
ICE BOUNDARY CROSSINGS

The analysis of ice boundary crossings involves several complications not present in the land boundary crossings. First, the boundary may not be sharp, in the sense of having a region totally ice covered abutting a region of open ocean. From the standpoint of data editing, however, the boundary must be defined as the region at which measured or computed ice data products are significantly influenced by ice. The second analysis problem is that accurate ground truth does not generally exist for the ice boundaries. This is not necessarily a major complication, since the problem is still basically to find a procedure for identifying the time at which data ceases to have the "normal" open ocean characteristics.

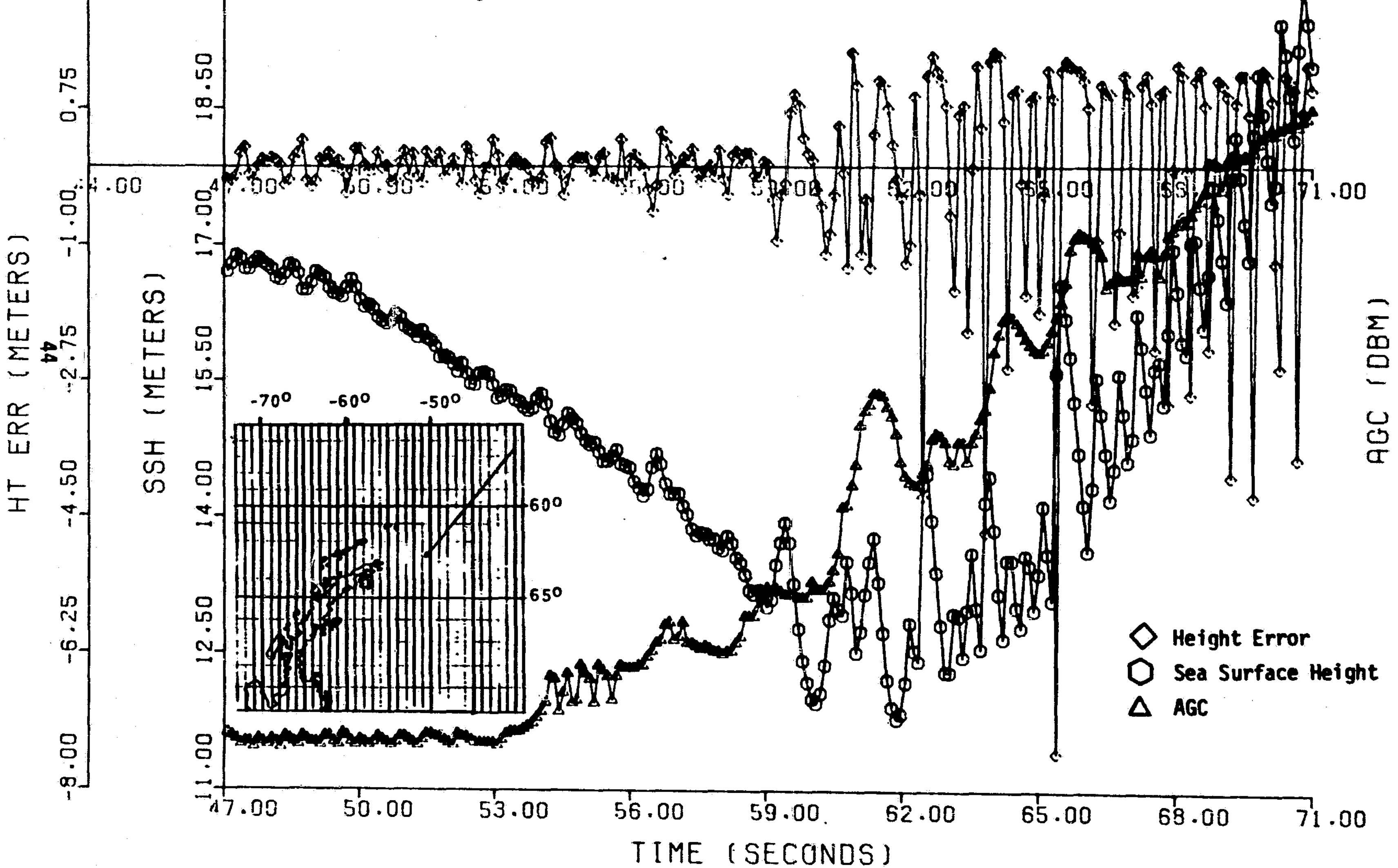
Figures 31-38 show eight samples of Seasat altimeter data for what are considered to be crossings from ocean to Antarctic region ice. In addition to sea surface height and height error, these figures also include AGC. This parameter is of interest because it is expected to show a large increase over ice, and also because height error may not reach the large magnitudes observed at ocean-land boundaries.

In general, the ice boundary crossings shown in Figures 31-38 show the following characteristics:

1. The sea surface heights over ice are much noisier than the sea surface heights over water.
2. The height errors also have larger amplitudes over the presumed ice regions. The 1 m height error amplitude, tentatively proposed in Section 3 for a water-land boundary crossing, is generally exceeded.
3. AGC shows a large increase over ice and begins, in most cases, 2-3 seconds or more prior to the boundary crossing indicated by sea surface height and height error.

The slope of the return pulse trailing edge was also computed for a couple of the ocean-ice crossings, plots for which are shown in Figures 39-40 and include approximate boundary crossing times as deduced from the sea surface height/height error/AGC plots in Figures 34 and 35. Although Figure 40 does show large positive slopes in the vicinity of the presumed boundary, the predominant characteristic is the slope variability. However,

Figure 31. Sea Surface Height, Height Error, and AGC for Seasat Altimeter Across Sea Ice Boundary on August 5, 1978 (19^h 59^m).



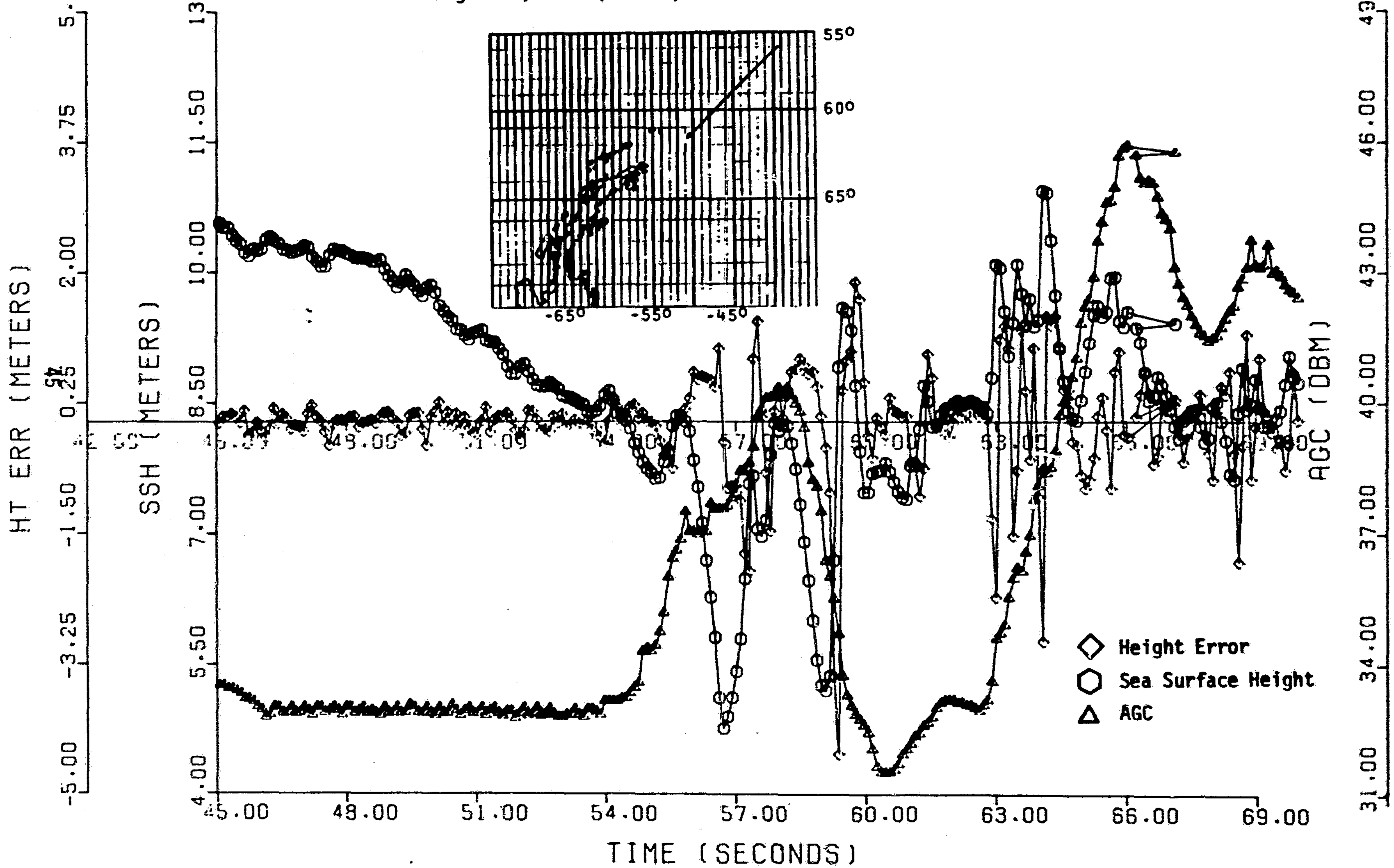


Figure 32. Sea Surface Height, Height Error, and AGC for Seasat Altimeter Across Sea Ice Boundary on August 2, 1978 (19^h52^m).

Figure 33. Sea Surface Height, Height Error, and AGC for Seasat Altimeter Across Sea Ice Boundary on July 31, 1978 (19^h14^m).

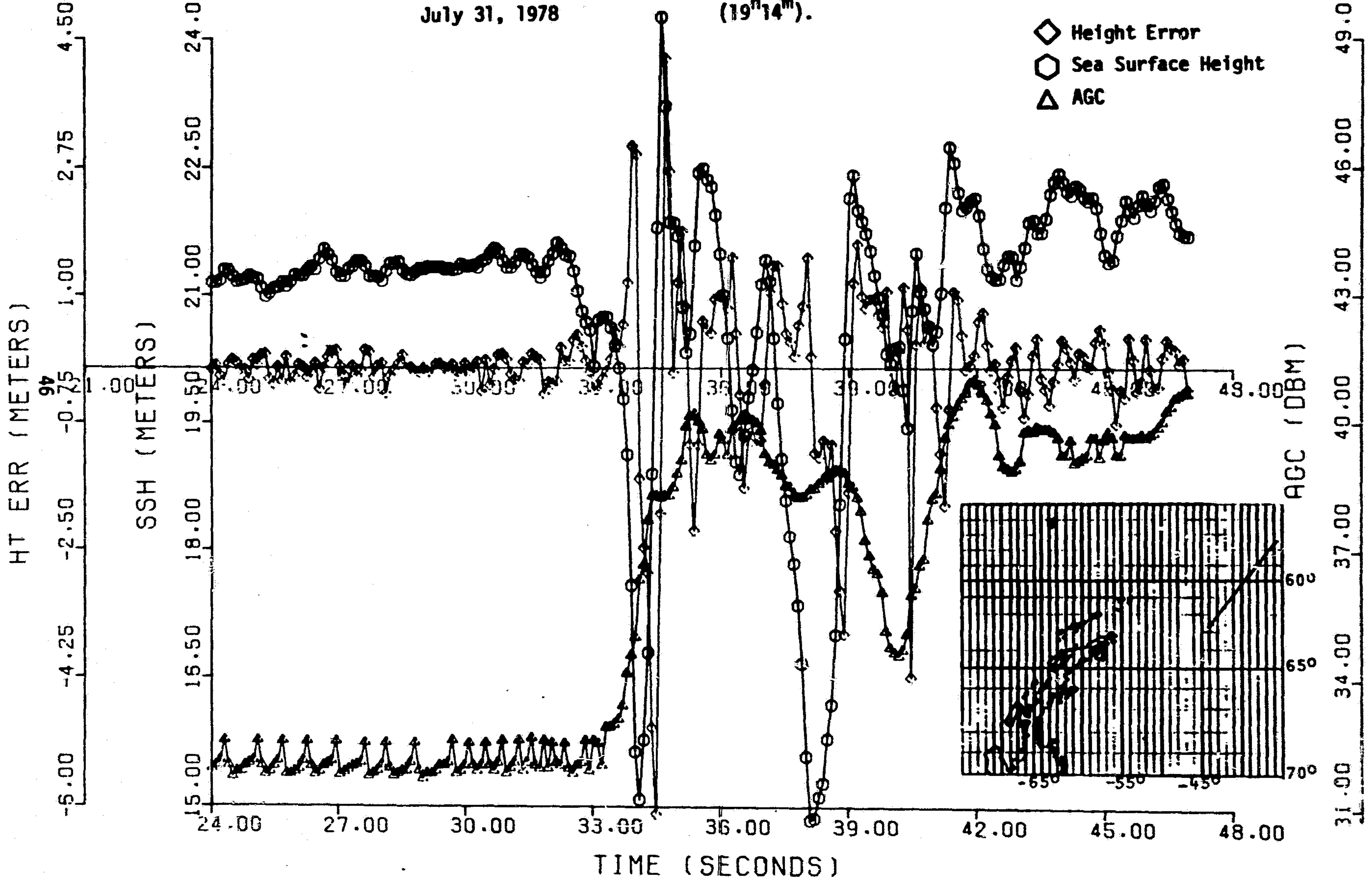


Figure 34. Sea Surface Height, Height Error, and AGC for Seasat Altimeter Across Sea Ice Boundary on July 26, 1978 (18^h28^m).

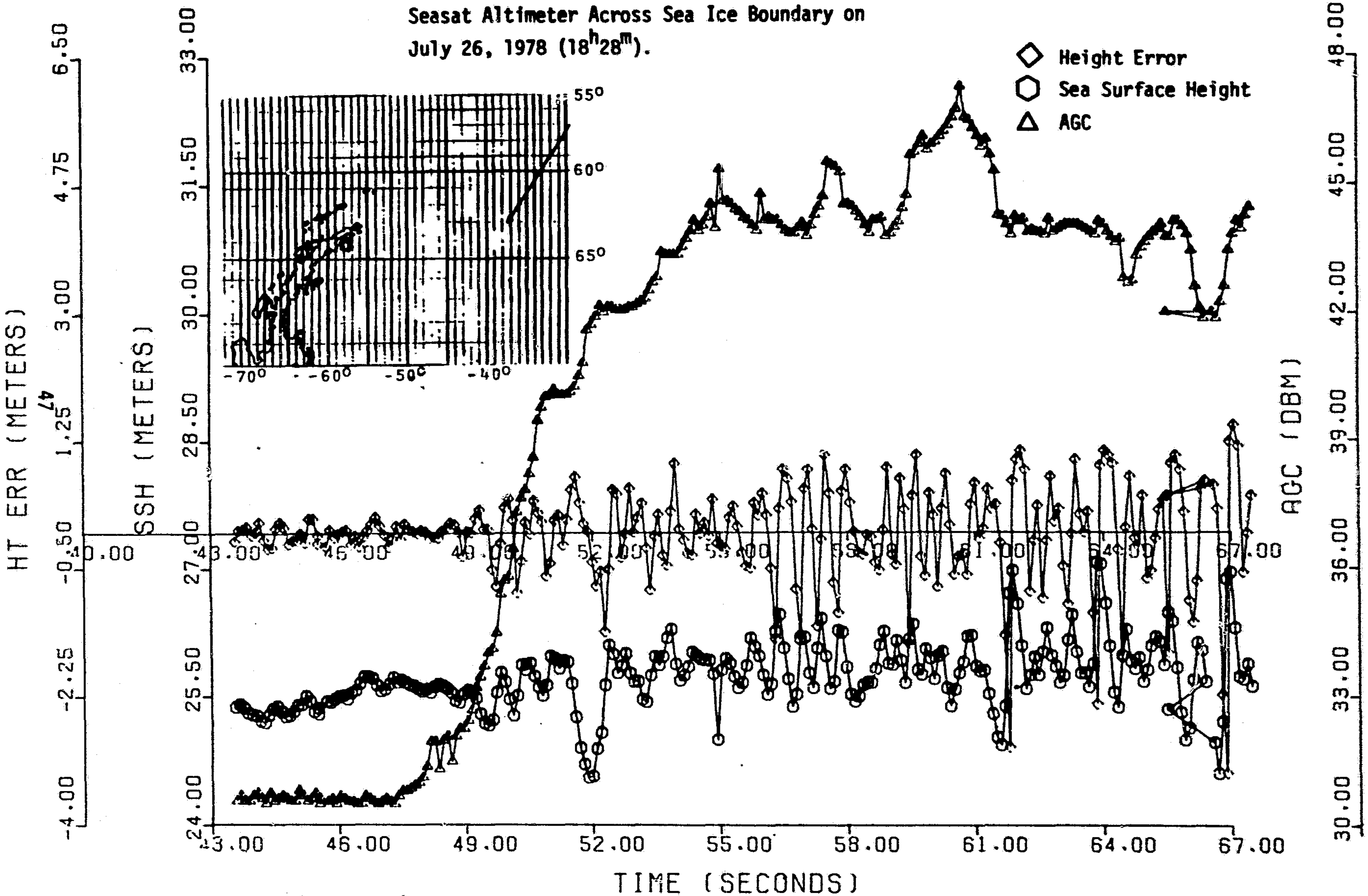
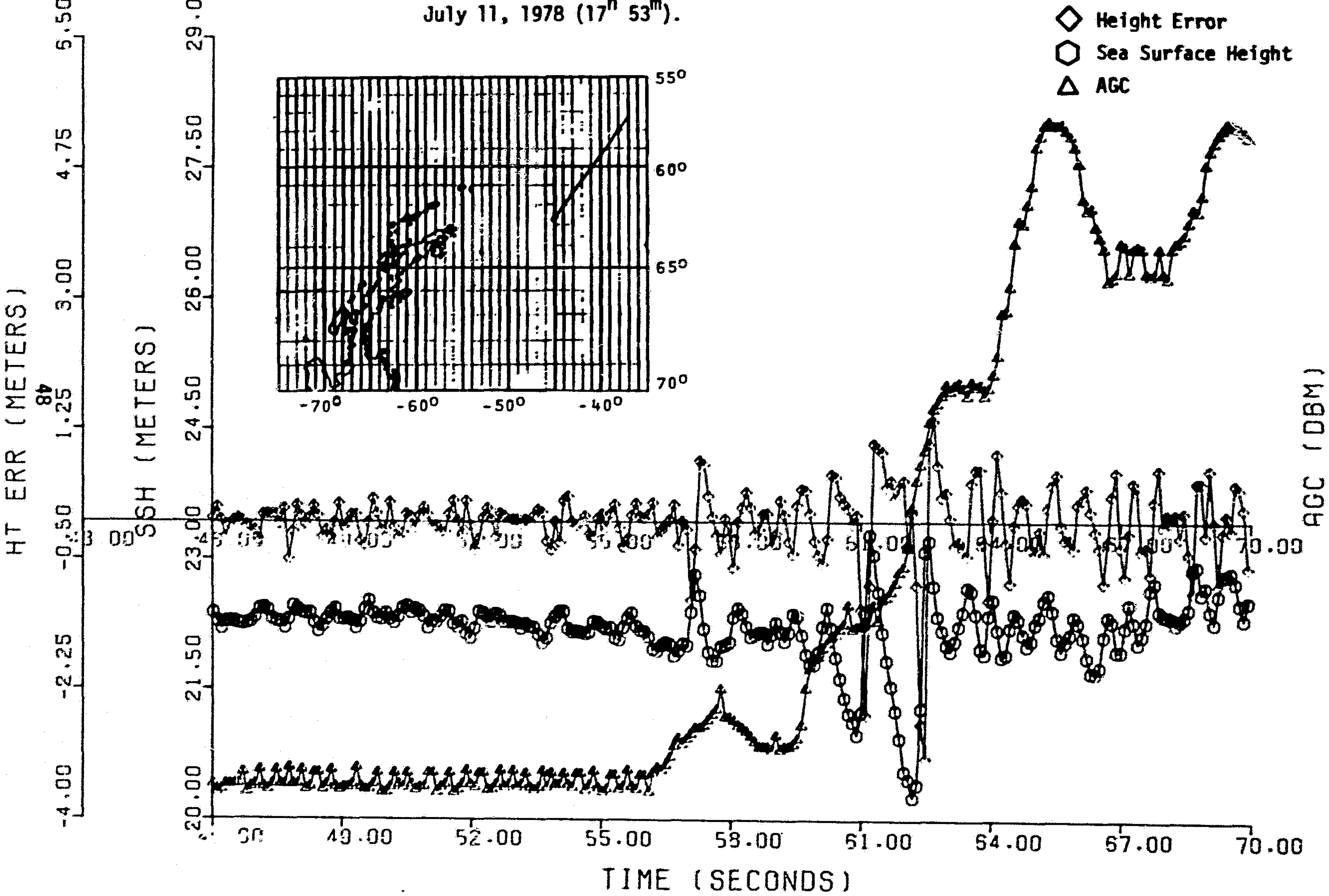


Figure 35. Sea Surface Height, Height Error, and AGC for Seasat Altimeter Across Sea Ice Boundary on July 11, 1978 (17^h 53^m).



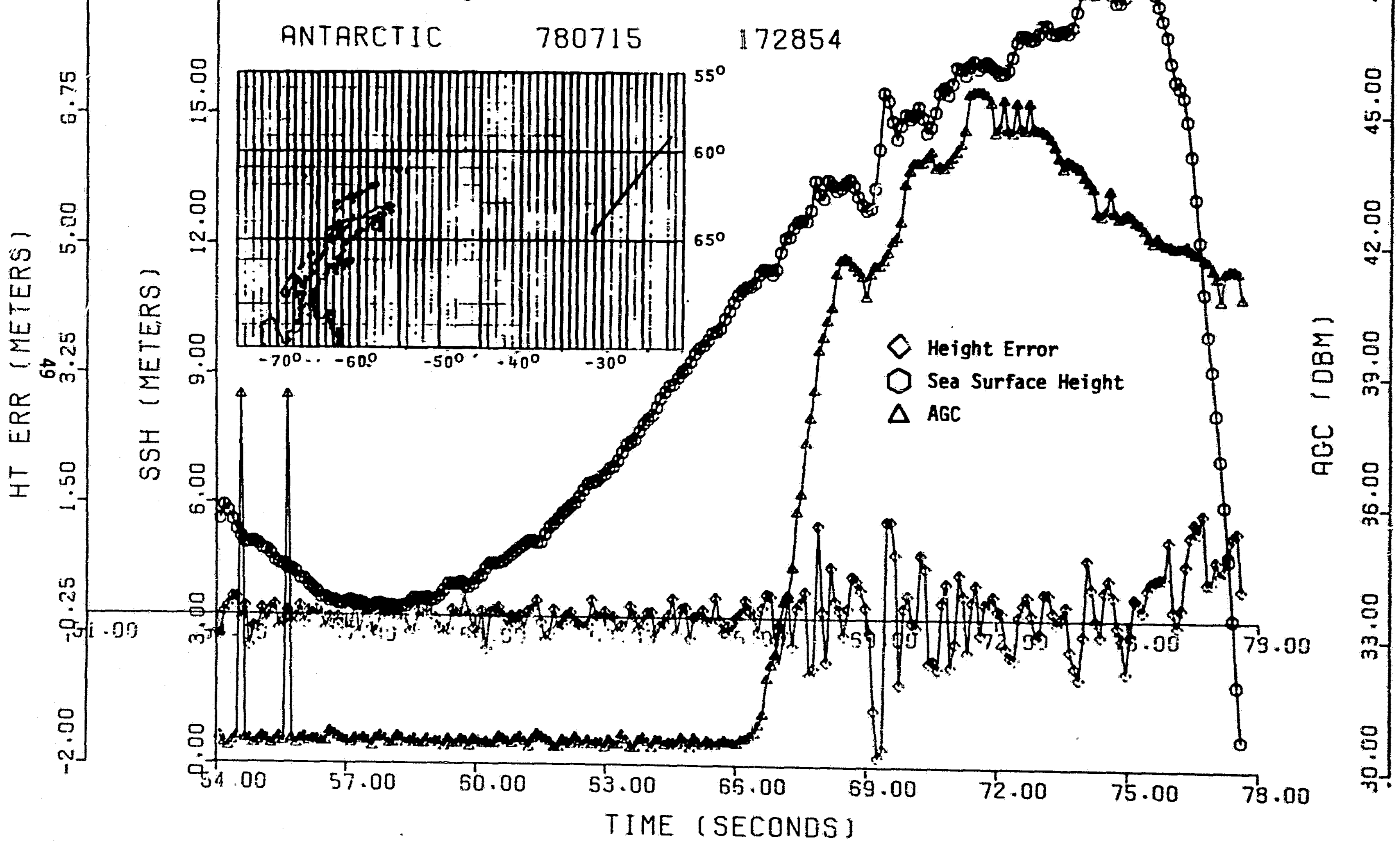


Figure 36. Sea Surface Height, Height Error, and AGC for Seasat Altimeter Across Sea Ice Boundary on July 15, 1978 (17^h 28^m).

Figure 37. Sea Surface Height, Height Error, and AGC for Seasat Altimeter Across Sea Ice Boundary on July 8, 1978 ($17^h\ 47^m$).

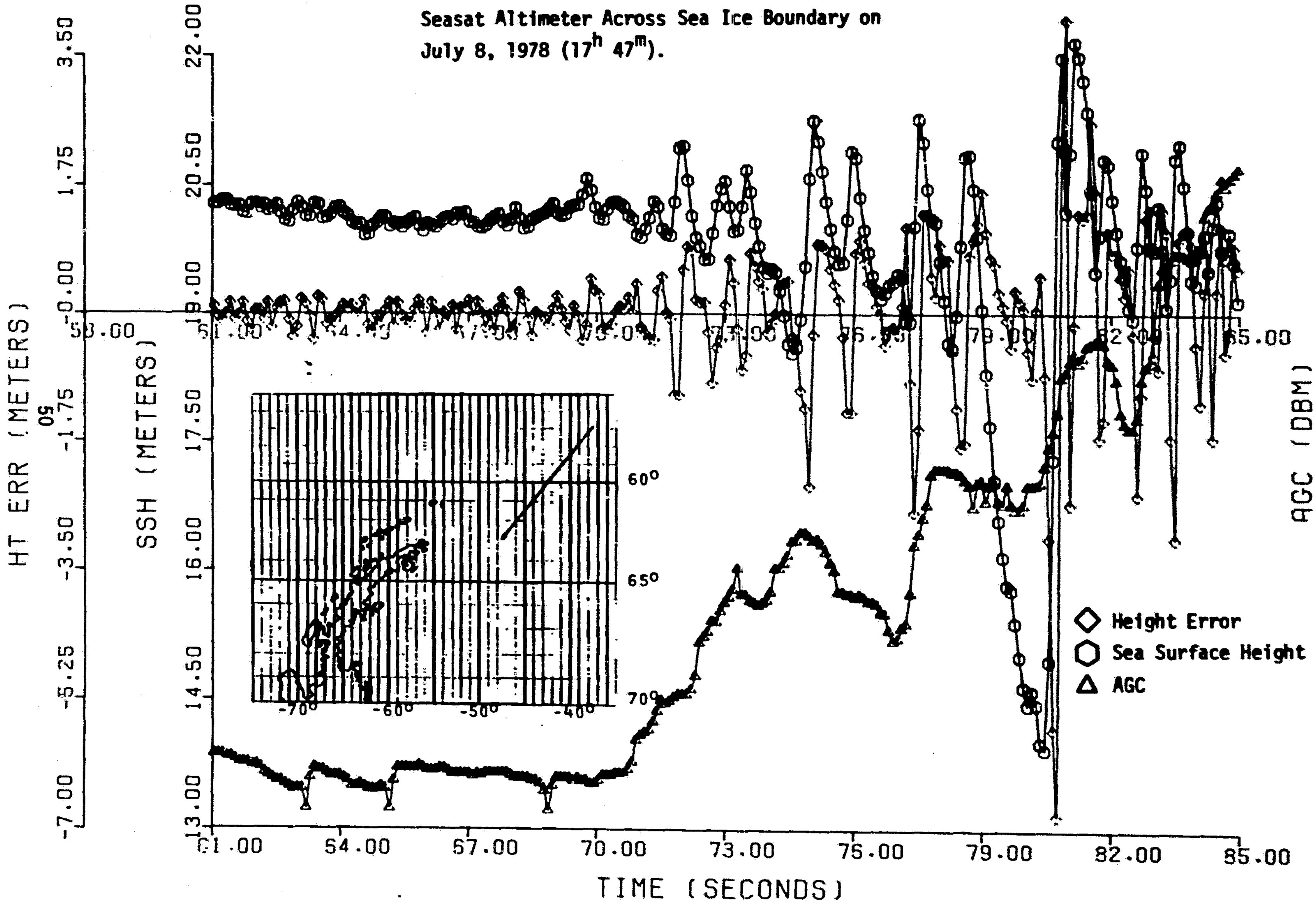


Figure 38. Sea Surface Height, Height Error, and AGC for Seasat Altimeter Across Sea Ice Boundary on July 7, 1978 ($16^h\ 37^m$).

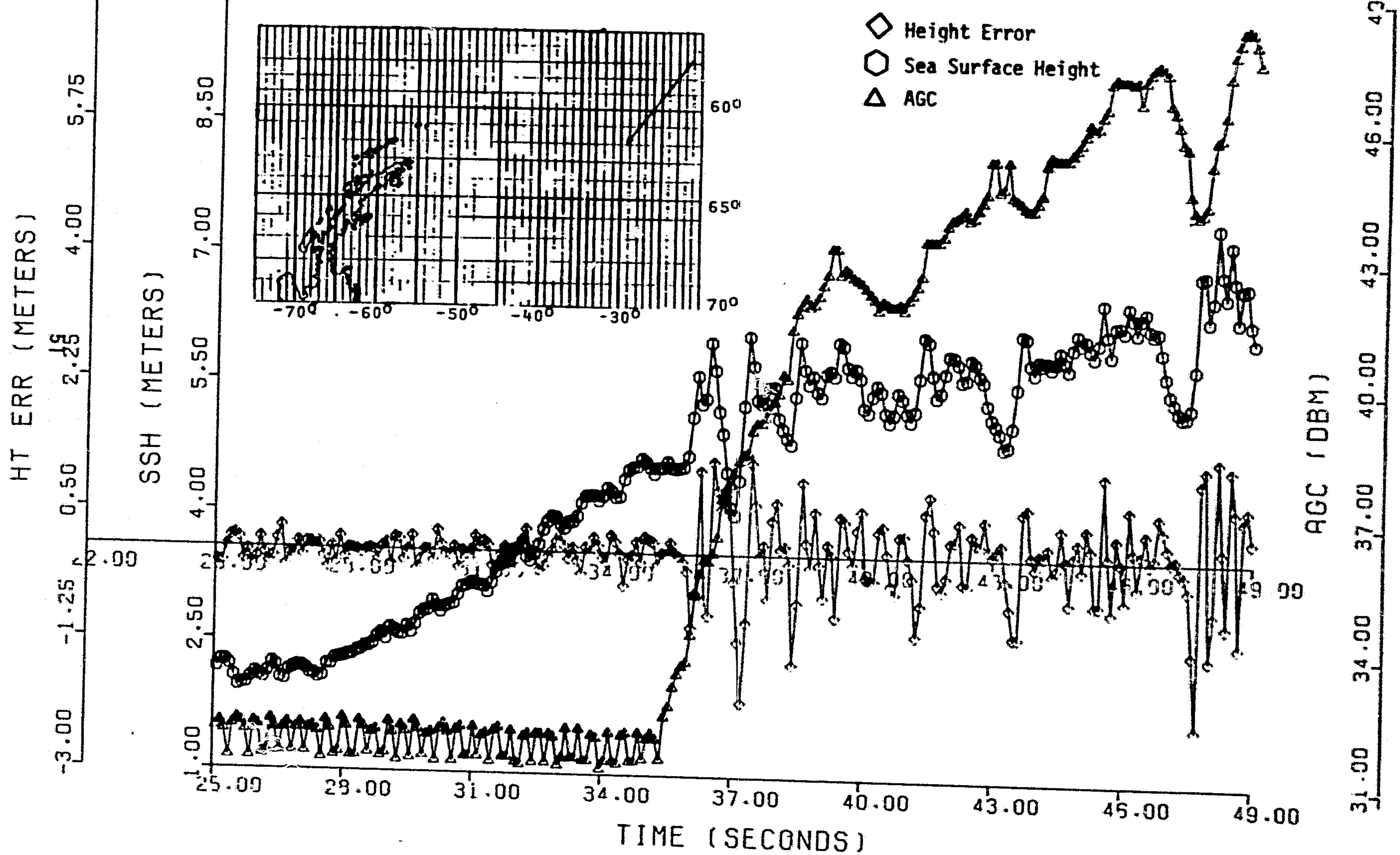


FIGURE 39. WAVEFORM TRAILING EDGE SLOPE NEAR ICE CROSSING BOUNDARY ON JULY 26, 1978

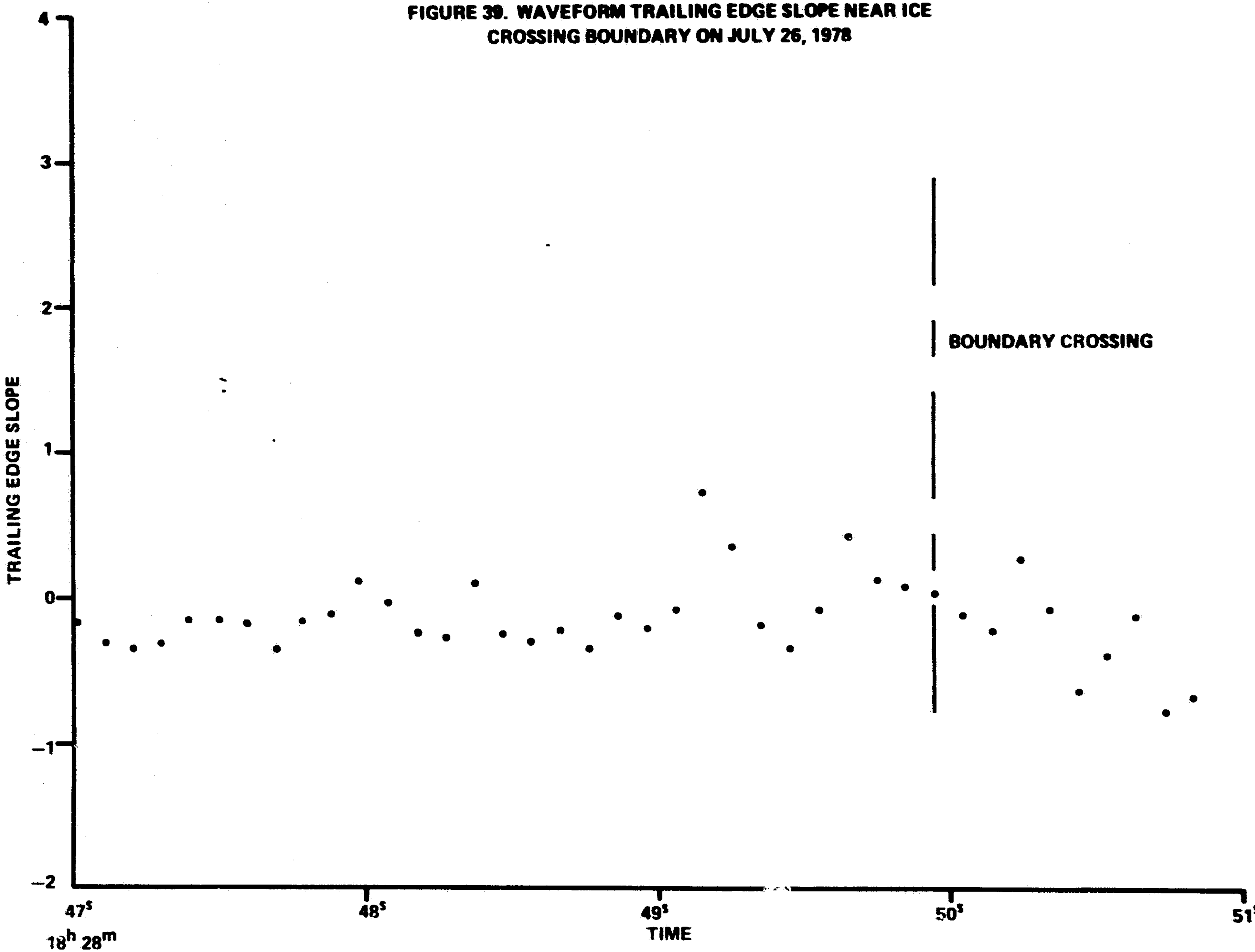
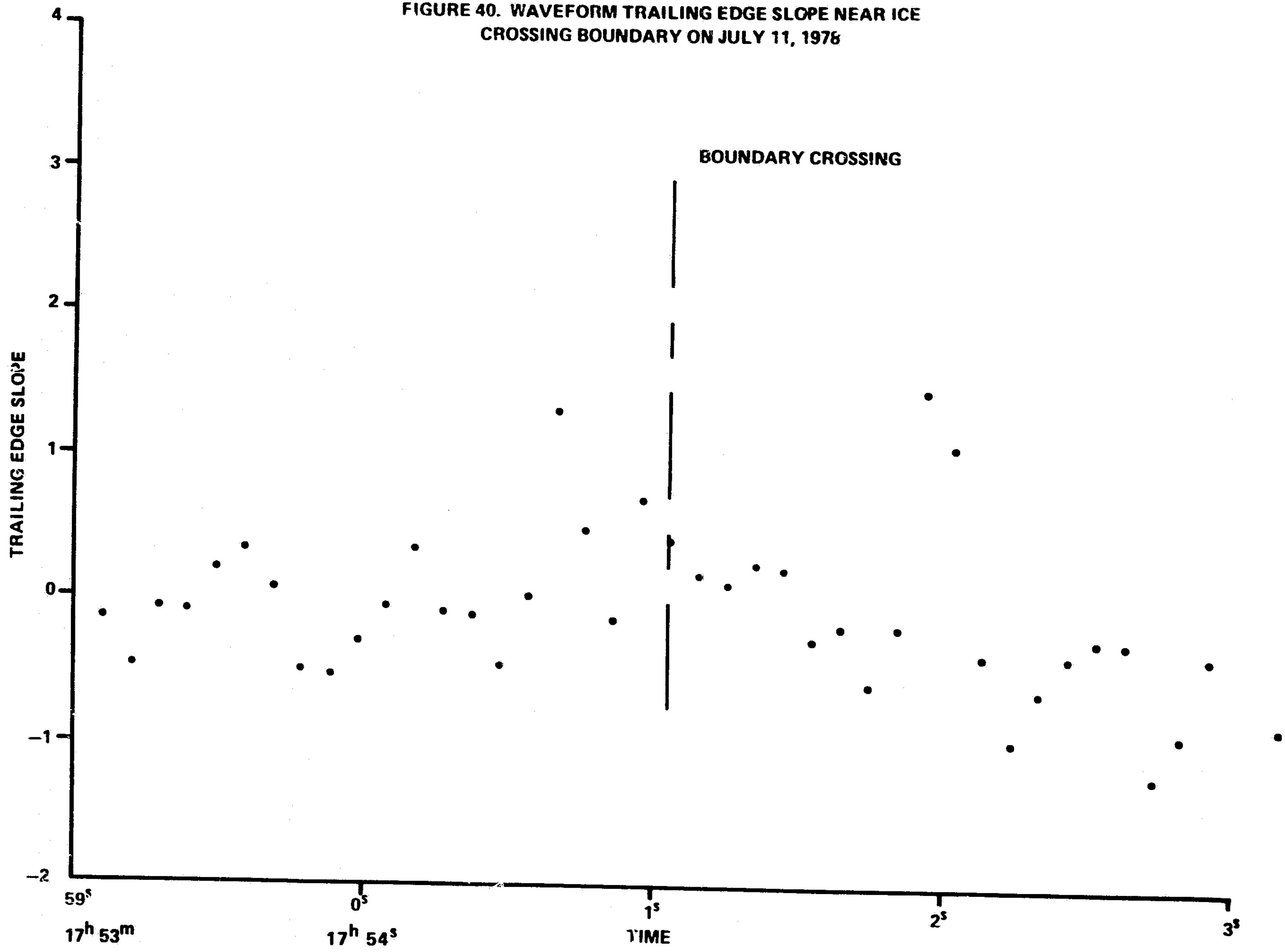


FIGURE 40. WAVEFORM TRAILING EDGE SLOPE NEAR ICE
CROSSING BOUNDARY ON JULY 11, 1976



the variability is much more evident in Figure 40 than in Figure 39, indicating that the surface roughness is considerably different between the passes. Again, the slope parameter does not appear to offer significant indication of a boundary that has not been provided by, e.g., height error.

Based on the characteristics discussed above, it is proposed that a reliable boundary detector might consist of something like the following:

- Height error anomalies in the sense of either a 1 m amplitude being exceeded, or an rms increase that is significantly above the normal ocean value, AND
- An increase in AGC significantly above either some fixed value, or significantly above a running average.

As indicated, the proposed detector depends on the intersection of two indicators.

Section 5.0
SUMMARY AND RECOMMENDATIONS

In Sections 3 and 4, Seasat boundary crossings from ocean to land and ocean to ice have been examined with the intent of developing a reliable indicator for the boundary crossings. For the ocean-land crossings, it was observed that:

1. A height error on the order of 1 m or greater was observed a high percentage of the time within 0.1 - 0.2 seconds of the boundary crossing.
2. A few cases were observed for which the large height error was not observed at the boundary. For these cases, strong instantaneous (0.1 second average) waveform distortion occurred within some 0.3 seconds past the crossing.

Based on these results, it is clear that a 1 m height error criteria is a simple boundary detection test with about a 90% detection probability, based on the statistics deduced from Table 1. For enhancement of this probability, some use must be made of either AGC or waveform information. However, as may be observed in Figures 31-38 for the ice crossings, and has also been noted for Seasat calibration crossings onto Bermuda (Kolenkiewicz and Martin, 1981), AGC does not show sharp variations as the boundary is crossed, but typically starts to increase one or more seconds away from the boundary. Since altimeter data products will have to be edited prior to land crossings (by ~1 second, e.g., for height data from a Seasat type altimeter), the boundary anticipation characteristic of Seasat AGC data would not per se preclude its utilization as a boundary detector, particularly for data editing purposes. But, based on the Bermuda calibration crossings, the AGC behavior near land is not consistent between passes, so the development of an appropriate land crossing algorithm based on AGC would appear to be very difficult.

This thus leads to the waveform information. Unfortunately, the simplified waveform product of trailing edge slope was found to provide minimal additional information, it is recommended that a full waveform fit to a theoretical model at the full data rate (~10/sec. for Seasat) be considered as a part of the boundary detection procedure. This fit can produce

- Height error
- SWH estimates, closely related to the trailing edge slope but after appropriate gate shifting due to height error
- RMS of fit to the theoretical curve.

A satisfactory boundary detection algorithm could be the crossing of a threshhold by any of these three parameters. It should be noted that the full data rate waveform fit will be somewhat noisy, and a limited amount of smoothing of output may be necessary.

For the ocean-ice crossings, AGC and height error were examined for a number of apparent ocean-ice boundaries in the Antarctic region. AGC always shows a large increase over ice and sometimes begins this increase 1-2 seconds prior to a boundary due to a partially frozen sea surface. Height errors do not generally have a large amplitude ($\sim$1 m) at the boundary, but do show a high rms over ice. However, the waveform fit procedure discussed above, possibly augmented by AGC, would be the approach recommended as most promising for a reliable ocean-ice boundary detector.

Very limited effort has been devoted in this study to crossings from land/ice to ocean. From several cases that have been examined, it is known that the large height error values do not occur at land-water boundaries. However, the waveform fit parameter test indicated above may be a major component of a test to determine that normal ocean data has been received.

REFERENCES

Hayne, G.S., "SEASAT-1 Waveform Sampler Gain Corrections", NASA/Wallops Flight Center, unpublished memorandum, February 2, 1981.

Kolenkiewicz, R., and C. F. Martin, "Seasat Altimeter Height Calibration", NASA Technical Memorandum 82040, March 1981.

Miller, L. S., "Topographic and Backscatter Characteristics of GEOS-3 Overland Data", JGR 84, 4045-4054, 1979.